TIGHT BINDING BOOK

THE OCEAN

A GENERAL ACCOUNT OF THE SCIENCE OF THE SEA

BY

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DEDICATED

TO MY ASSISTANTS IN THE "CHALLENGER OFFICE" DURING THE PAST THIRTY-SEVEN YEARS

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THE OCEAN

CHAPTER I

HISTORICAL NOTES: METHODS AND INSTRUMENTS OF DEEP-SEA RESEARCH

Historical.—Many of the phenomena exhibited at the surface of the sea were regarded with terror by primitive man, and poets have sung the praises of that hero who first shaped a hollow canoe out of a fallen tree and thus initiated shipbuilding and the navigation of the open ocean.

The early Greeks had a practical knowledge only of the enclosed Mediterranean, which they called Thalassa, but they had also some knowledge of what was called the great River of the Ocean beyond the Pillars of Hercules, as well as of the Arabian Gulf, which was called the Erythræan Sea. They are said to have derived their information concerning this great outer ocean from the Phœnicians. Necho, an early Egyptian king, is reported to have ordered his Phœnician sailors to sail down the east coast of Africa,

and to return to the Mediterranean by the Atlantic. Whether this voyage was accomplished or not, the Phœnicians appear to have reached the southern hemisphere, for they reported that at their most southerly point they had the sun on their right hand—a statement that could hardly have been invented, and was of course true if they rounded Africa.

It was a great event in the history of oceanography and of the world when, in the fourth century before our era, the Greek, Pytheas, burst into the Atlantic with his ships, and sailed as far north as the coasts of Great Britain. It was a similarly great event when Hippalus, about the first century before our era, discovered the monsoon winds of the Indian Ocean, for after that coast routes were abandoned, and voyages of six months' duration across the open ocean were made to the coasts of India.

The thirty years between 1492 and 1522 are ever memorable for the great advance made in our knowledge of the surface of the earth. Within this period Columbus sailed across the Atlantic to America, Da Gama rounded the Cape of Good Hope and reached India, and the survivors of Magellan's expedition in one of his ships completed the first circumnavigation of the globe—a whole hemisphere

was added to the charts of the known world almost at a single bound.

It is interesting to note that Magellan, when crossing the Pacific in 1521, attempted to sound the open ocean; his short line failed to reach the bottom, and he naïvely concluded that he had discovered the deepest part of the ocean.

The early voyages in the sixteenth and seventeenth centuries led to a vast increase of knowledge of the superficial extent of the various oceans, their currents, tides, winds, temperature, and salinity. True deep-sea soundings were taken by Captain Cook during the second half of the eighteenth century, by Captain Phipps in the Arctic in 1773, by Sir John Ross in the Arctic in 1818, and by Sir James Clark Ross in the Antarctic in 1840, all these, except when in very deep water, being fairly accurate.

The proposal to lay an electric cable between Europe and America gave a great impetus to oceanographical investigations, and led to great improvements in the apparatus for taking deep-sea soundings. About 1850 Brooke introduced a method of detaching the heavy weight used to carry down the line and tube; on striking the bottom the weight was left there, and the tube with its sample of bottom-deposit was hauled up to the

surface. After this time deep-sea soundings became much more frequent and more accurate.

About the year 1840 Edward Forbes, as a result of researches in the Ægean Sea, came to the conclusion that both plants and animals ceased to exist in the ocean beyond a certain depth, the zero of vegetable life being at a less depth than that of animal life. The zero of animal life he placed at about 300 fathoms, and his views were very largely applied by naturalists to the whole ocean. Investigations subsequently undertaken by Michael Sars, Wyville Thomson, W. B. Carpenter and others on the Atlantic coasts of Europe showed that animal life existed at a depth of one or two miles.

These and similar researches led to the despatch of the great "Challenger" Expedition by the British Government in the year 1872 for the express purpose of examining the physical and biological conditions of the great ocean basins. The "Challenger" had on board a staff of scientific observers, who during a circumnavigation of the world lasting for three and a half years made continuous observations, on the depth, temperature, salinity, currents, animal and vegetable life, and deposits, at all depths throughout the great oceans. The results of this expedition

were published by the British Government in fifty quarto volumes, and these have formed the starting point for all subsequent deep-sea investigations, and laid down the broad general foundations of the modern science of oceanography.[1]

During the past thirty years nearly every civilised nation has sent forth expeditions to undertake deep-sea researches, and during

[1] The term Thalassography has been used, largely in the United States, to express the science which treats of the ocean. The term Oceanography is, however, likely to prevail. The Greeks appear to have used the word Thalassa almost exclusively for the Mediterranean, whereas the almost mythical "oceanus" of the ancients corresponds to the ocean basins of the modern geographer. In recent times I believe the word Oceanography was introduced by myself about 1880, but I find from Murray's English Dictionary that the word "oceanographie" was used in French in 1584, but did not then survive.

The words Oceanography and Oceanology are not "mongrel" words; on the contrary, they are both absolutely correct formations, on such analogies as *geography*, *topography*, and *theology*, *demonology*, *anthropology*, *zoology*. The Greek dictionary knows such a word as *thalassographos*, but not *oceanographos*. But to insist on this point would be the merest pedantry, for even now it is not of the Atlantic, Pacific, and Arctic Seas that we speak, but of the oceans bearing those names. Sutherland Black says: "By thalassography the Greek dictionary chiefly means the description of the Mediterranean. A very myopic pedant might raise some scruple over *-graphy* on the ground that a mythographer is a 'writer' of myths, and a logographer a 'writer' of prose; but then a topographer is not a writer of places, but a describer of them: so also with geographer."

the past twelve years an International Commission has been engaged in the scientific exploration and study of the North Sea and Norwegian Sea. In addition marine laboratories have been established in many parts of the world for the purpose of carrying on the systematic examination of the ocean and its inhabitants. The general result has been that all the methods and instruments used in deep-sea work have been much improved. It is impossible in this little book to follow all the developments that have taken place in this direction, but a short statement concerning the methods and instruments now generally in use may be instructive and interesting.

Methods and Instruments.—In making observations at the surface of the sea all the ordinary methods and instruments in use among meteorologists and physicists are available, but whenever we commence to explore the deeper waters of the ocean other methods must be adopted and other instruments invented. While functioning beneath the surface the instruments are removed from direct observation, and various contrivances must be used to control their action. The difficulties which have to be overcome add very greatly to the interest of all deep-sea investigations. Thermometers for deep-sea work must be protected from pressure on the

bulb containing the mercury. A reversing thermometer may be used, but a contrivance must be arranged for reversing it after it has taken the temperature of the water at a given depth. Water-bottles must be lowered empty or open at both ends, and closed at any given depth from which a sample may be desired. It is the same with the appliances for ascertaining the intensity and quality of sunlight at a given depth: the apparatus with the sensitive plates must be sent down closed, then opened to expose the plates, then closed again before being hauled to the surface.

A great many of these operations are accomplished by sending messengers—small metal weights—down the line to release springs or to open catches. The time taken for these messengers to run down a line of two or three miles is very great, but with experience much time may be saved by letting the messengers go while the line is still running out. Another contrivance is an attached propeller, which, on being pulled a few fathoms towards the surface, revolves and releases a spring, thus closing a bottle or reversing a thermometer.

Sounding.—During the "Challenger" Expedition some experiments were made with wire sounding lines, but fine hemp lines were always used in the regular work, and in very deep soundings the time when each

100-fathoms mark went over the ship's side was carefully noted. When there was a sudden change in the rate at which the line ran out, it was known that the bottom had been reached, and the depth was then recorded. Deep soundings, even in 4000 fathoms, carefully taken in this way are believed to be correct to within 25 fathoms.

A marked advance was made when the late Lord Kelvin introduced piano wire for sounding purposes. In the Lucas sounding-machine (see Plate I.), which at the present time is the one most in use, the moment when the weight strikes the bottom is automatically indicated on the machine, and the running-out of the wire is stopped. Soundings taken with this machine are believed to be correct to within one fathom, even in deep water. A sounding in 2000 fathoms now requires about 45 minutes from start to finish, *i.e.*, from the time the lead is let go till it is hauled on deck with a sample of the bottom-deposit, and one in 3000 fathoms about 75 minutes. The "Challenger's" deepest sounding in 4475 fathoms occupied about 2½ hours. The single-strand piano wire used for sounding is only about one-twentieth of an inch in diameter; a three-strand wire of the same diameter is also used, while a seven-strand wire with a diameter of one-sixteenth of an

inch has recently come into use in the Navy. The stranded wire used with water-bottles and thermometers is about one-eighth of an inch in diameter.

Trawling and Dredging.—During the "Challenger" Expedition strong hempen lines were used. Sometimes a hempen line eight miles in length was out astern of the ship when trawling in 3000 fathoms. A very great advance was subsequently made when the late Alexander Agassiz introduced wire ropes, about one-third of an inch in diameter, for these operations. The use of piano wire for sounding and steel rope for trawling and dredging is now almost universal. The dredges used on board the "Challenger" (see Plate I.) were 3 to 5 feet in width, and the trawls had beams 10 to 17 feet in length, the smaller size being used in very deep water. On board the "Challenger" a trawling in 3000 fathoms used often to take from 12 to 14 hours. The trawls and dredges are now of many different designs—from the smallest oyster dredge to the large otter trawl with a span of 50 feet. This latter appliance was used successfully by the "Michael Sars" Expedition of 1910 in 3000 fathoms (see Plate I.).

Tow-Nets and Vertical Nets.—For capturing the animals and plants swimming or floating at the surface and in intermediate waters

various forms of tow-nets have been devised. Those used during the "Challenger" and other early expeditions were simply long bags of muslin or bunting or silk, tapering from the metal hoop forming the mouth, about a foot in diameter, to the opposite closed end of the net. They were towed horizontally, with a weight fixed on the line a short distance in front of the opening, or vertically by being tied to the sounding or dredging line (see Plate I.). Subsequently much larger nets and pelagic trawls have been employed, and many attempts have been made to construct nets and traps that could be opened and closed at any desired depth. The material of which such nets is now made is the same as that used by millers in separating the various grades of flour; it is a fine silk, made with meshes of various sizes, the finest make having about 6000-6500 meshes to the square centimetre. The meshes are pentagonal in shape, and the web is so constructed that they are not easily distorted.

During the recent "Michael Sars" Expedition various nets, both open and closing, and pelagic trawls were used with varying success, but the best results were obtained by towing simultaneously for long distances a number of pelagic appliances (sometimes as many as ten) attached to two lines at certain definite

intervals, so that the approximate depth of each haul was known (see Plate I.). The results obtained were then controlled by using vertical closing nets.

Centrifuge.—Recent pelagic investigations have shown that a great many marine organisms are so small that they pass through the meshes of even the finest silk nets. These minute organisms may be studied by centrifuging samples of sea-water taken by the water-bottle from various depths. The "Michael Sars" used a large centrifuge driven by one of the small steam winches on board. This had six glasses, and as much as 1200 cubic centimetres of sea-water could be centrifuged at one time. It made 700 to 800 revolutions in one minute, and after eight minutes the organisms were all collected at the bottom of the glasses. The clear water was then poured away, and the deposit after being rinsed was put into a smaller glass with a tapering bottom, where it was subjected to the action of a small hand-centrifuge, such as is used by physiologists. In this way all the contents of say 300 cc. of sea-water were collected in one drop, which was examined in a counting chamber beneath the microscope.

Deep-Sea Thermometers.—Six's maximum and minimum thermometer was one of the earlier forms used in taking deep-sea tempera-

tures, and as modified by Miller and Casella was the one mostly in use during the "Challenger" and other expeditions of the same or an earlier period. This thermometer is satisfactory for work in the open ocean, where the temperature as a rule decreases gradually from surface to bottom. Towards the polar regions and in some enclosed seas, however, layers of different temperatures may lie one above another, and such conditions would not be disclosed by the Six form of thermometer; it has, therefore, been replaced to a large extent by another form, which may be reversed, and the temperature thereby registered, at any desired depth.

The reversing thermometer (see Plate I.) is sent down with the bulb lowermost; there is a narrowing of the tube just above the bulb, and the length of the column of mercury above the constriction depends upon the temperature. On being reversed the mercury is broken off at the constriction, the bulb being now uppermost, and the column of mercury that was above the constriction falls down, the temperature at the moment of reversal being read off in the reversed position. The reversing thermometer has been modified and improved by Negretti and Zambra and by Richter, so that at the present day it is a very efficient instrument. Occasionally an error may be

introduced by the faulty formation of the constriction, which may lead to the mercury not always being broken off at the same point.

Now that the greatest possible accuracy is called for in deep-sea work, it is not unusual to send down two reversing thermometers side by side in order to obtain corroboration as to the actual temperature at the depth of reversal.

Water-bottles.—Recently a reversing water-bottle has come into use, designed to carry one or two reversing thermometers, so that a temperature-reading and a water-sample are secured at one and the same time (see Plate I.). Another method of attaining this object is by means of insulating water-bottles, which protect the contained samples from temperature-changes while being hauled up to the surface, so that the temperature of a sample immediately on being brought on board may be supposed to indicate practically the temperature at the depth where the apparatus was closed. An instrument of this kind is the Pettersson-Nansen insulating water-bottle.

For obtaining a water-sample from the surface an ordinary bucket may be used, and in quite shallow water a stoppered bottle may be sent down attached to the line in such

a way that a jerk pulls out the stopper. In deeper water a stopcock water-bottle was employed during the "Challenger" Expedition for intermediate samples and a slip water-bottle for bottom samples.

Photometer.—For investigating the penetration of sunlight into the sea and the intensity and composition of that light at different depths, various forms of photometric apparatus have from time to time been employed. The latest is that designed by B. Helland-Hansen (see Plate I.) and used by him successfully during the recent cruise of the "Michael Sars" in the North Atlantic. It consists of a framework, on which two cubes, fitting one inside the other, slide up and down, the smaller cube having five openings, one on each of the four sides and one on the top, for the exposure of photographic plates with or without colour filters. The cubes are carried into the dark room, and the plates are placed in the smaller cube, which is then enclosed inside the larger cube and thus effectually protected from the light. The two cubes are suspended in the upper part of the frame, and the apparatus is lowered to the desired depth, when a messenger is sent down the line to release the smaller cube, which falls to the bottom of the frame, thus exposing the plates. After the necessary interval a second

messenger is sent down to release the larger cube, which falls and covers the smaller one, thus ending the exposure. The apparatus is hauled up and the cubes taken into the dark room for the development and fixing of the plates.

Current Measurements.—For measuring the velocity and direction of currents in the sea many devices have been employed. Information regarding surface currents may be obtained from the drift of floating objects, such as drift-bottles, wreckage, icebergs, vessels frozen in the ice of polar regions, and movements of water-masses at the surface and under it may often be traced by studying their physical and chemical properties (temperature, salinity, dissolved gases). For the direct measurement of undercurrents it is necessary to use a current meter of somewhat complicated construction. The latest form is that designed by V. W. Ekman.

Hydrometers.—The direct determination of density may be made by means of the hydrometer, a glass cylinder which floats in water. Densities so found are re-calculated by means of tables to a standard temperature. Owing to the uniform composition of sea-salts a definite density at a definite temperature corresponds rigidly to a definite salinity. Hence, by referring to tables the salinity of

sea-water can be found from its density at standard temperature.

Densimeter.—For the determination of the relative densities of sea-water samples, a differential densimeter was recently introduced by J. J. Manley. It is somewhat complicated in design, and was at first intended for use in a laboratory on shore. The apparatus has been modified so as to adapt it for use on board ship, and a series of observations has been carried out by N. P. Campbell during a voyage to Ceylon on board one of the Orient mail steamers, apparently with good results.

For methods of determining salinity see Chapter III.

CHAPTER II

THE DEPTH OF THE OCEAN

ARCHDEACON J. H. PRATT, the mathematician, in discussing the pendulum investigations among the Himalaya mountains, appears to have believed that the great Pacific Ocean could only be explained on the assumption of "some excess of matter in the solid parts of the earth between the Pacific Ocean and the earth's centre, which retains the water in its place, otherwise the ocean would flow away to other parts of the earth." According to this view the existence of the oceans in their present positions is referred to an excess of density in the sub-oceanic portions of the globe. In one sense this is confirmed by recent geodetic and gravity observations, but in all probability the sub-oceanic heaviness does not extend to depths greater than thirty miles. The great centrosphere of the earth is inferred to be more or less homogeneous in structure and composition, and also as rigid as steel, whatever the nature

and condition of the materials of which it is composed. On the other hand, it is known that the rocky crust is heterogeneous in composition to the depth of several miles.

The gravitational attraction of emerged land causes a heaping-up of ocean waters along continental shores. In consequence of this it has been stated that the waters of the Mid-Indian Ocean are lowered fully 1500 feet by the attraction of the elevated regions of the Himalayas. More recent calculations, however, show that the total deformation of the ocean's surface from that which would be assumed by a true spheroid of revolution is not likely to be more than 300 or 400 feet. Other causes, such as difference of barometric pressure, the action of winds, temperature, evaporation, precipitation of rain, and the inflow of rivers, all tend to alter the level of the ocean, the surface of which is really a very complicated one, and must at some points be further removed from the geometrical centre of the earth than at others. It is to this complicated surface of the ocean (or of the geoid) that all measurements of height and depth are referred.

Areas at different Depths.—The land-surface of the globe covers about 57 millions and the water-surface about 140 millions of English square miles: in other words 29

per cent. of the surface of the globe consists of land and 71 per cent. is covered by water. The depth-soundings which have up to the present time been taken in the ocean are extremely numerous, more especially in the shallow water close to land. It is not practicable to estimate the number of soundings in depths less than 1000 fathoms (6000 feet), but the numbers recorded from depths exceeding 1000 fathoms in the annual blue-books published by the British Admiralty between 1888 and 1910 are as follows :—

1000-2000 fathoms	...	6000	soundings.
2000-3000 ,,	...	3250	,,
3000-4000 ,,	...	300	,,
4000-5000 ,,	...	17	,,
Over 5000 ,,	...	3	,,
Total exceeding 1000 fathoms		9570	,,

To this must be added a very large number of soundings taken by other ships not recorded at the Admiralty. The Prince of Monaco, the Berlin Institut für Meereskunde, and the writer have published maps showing practically all the deep-sea soundings known up to the present time.

From these data the estimated areas within the different zones of depth are given in the following table :—

Depth.	Estimated area in English square miles.	Percentage of total Ocean-Floor.
Between 0 and 1000 fms.	22,000,000	16
„ 1000 „ 2000 „	27,000,000	19
„ 2000 „ 3000 „	81,000,000	58
„ 3000 „ 4000 „	9,800,000	7
„ 4000 „ 5000 „	195,000	[less than 1]
Exceeding 5000 fathoms	5,000	
	140,000,000	100

It will be seen from an examination of this table that only 16 per cent. of the ocean-floor lies between the shore-line and 1000 fathoms (6000 feet), so that 84 per cent. lies deeper than 1000 fathoms; again, only about 7 per cent. lies deeper than 3000 fathoms (18,000 feet), so that 77 per cent. lies between the depths of 1000 and 3000 fathoms, while more than one-half of the entire floor of the ocean (58 per cent.) is covered by depths between 2000 and 3000 fathoms. It is probable that these estimates are not far from the truth, for it is remarkable how little the contour-lines have been altered by the great number of deep soundings that have been recorded during the last ten or twelve years.

Deeps.—There is a special interest attached to the greater depths of the ocean, so the writer some years ago called all those areas where the depth exceeds 3000 fathoms (18,000 feet) "deeps," and gave them distinctive names, generally after exploring ships, navigators and scientific men, thus following the practice of naming mountain peaks. Fifty-seven such "deeps," based upon some 500 soundings, are now known: 32 in the Pacific, 18 in the Atlantic, 5 in the Indian Ocean, and 2 in the Southern Ocean. Their positions are shown in Plate II. They vary greatly in outline: in some cases they are very irregular or basin-like, but often they are trough or trench-shaped and relatively close to continental land. Some, like the Valdivia Deep in the Southern Ocean and the Murray Deep in the North Pacific, are believed to cover a large area, while a few are very small, being based on single isolated soundings. The total area covered by these deeps is altogether only about 7 per cent. of the ocean-floor. Occasionally a cone-like elevation with a depth on its summit of less than 3000 fathoms rises from the centre of a deep.

Deepest Soundings.—Two deeps in the Atlantic and seven in the Pacific have depths exceeding 4000 fathoms, 46 soundings in depths greater than 4000 fathoms having

been recorded up to the present time. Only 8 soundings are recorded in depths exceeding 5000 fathoms (30,000 feet). Three of these occur in the Aldrich Deep in the South Pacific near the Friendly and Kermadec Islands, where the deepest cast is 5155 fathoms. Four occur in the North-West Pacific in the Challenger Deep, the deepest cast being 5269 fathoms, while the greatest known depth, of 5348 fathoms, was recorded in the Swire Deep, off Mindanao, by the German ship "Planet" in 1912. This greatest known depth in the ocean is 32,089 feet, or 409 feet more than six English miles. If the highest known mountain (Mount Everest in the Himalayas, 29,002 feet) could be placed in this area of the Pacific, its summit would be covered by the waters of the ocean to a depth of 3087 feet.

It is only in the Pacific that depths exceeding 5000 fathoms are known. The deepest sounding in the Atlantic is 4662 fathoms (north of the West Indies), and in the Indian Ocean the greatest depth is 3828 fathoms (south of Java). It is unlikely that the greatest depth is yet known, but when we remember the small number of soundings in depths greater than 5000 fathoms, and the relatively small area which the deeps of the ocean occupy, it seems most improbable that depths greater than 6000 fathoms—six geo-

graphical miles—will ever be recorded in the ocean. The extreme variation in the irregularities of the external surface of the earth's crust, so far as is known at the present day, is 61,091 feet, or over eleven and a half English miles—that is between the top of Mount Everest and the bottom of the Swire Deep.

Submarine Elevations.—With the progress of our knowledge regarding the depth of the ocean the number of isolated submarine cones made known from time to time has been greatly increased. Some of these are deeply submerged, while others rear their summits so near to the surface as to become dangerous to navigation. With the exception of a few situated near continental shores, they are probably all of volcanic origin, although some of them are now covered with a white mantle of calcareous ooze or coral growths. Many of the coral atolls and other oceanic islands are merely the summits of such volcanic cones. In the vicinity of these submarine cones the sea-floor may be very irregular, and in one or two cases there is evidence of precipitous cliffs on the submerged slopes, but, generally speaking, what we know of ocean soundings leads us to suppose that the sub-oceanic slopes are extremely gentle. The steepest gradients usually occur on the continental slope in depths of 100 to 1700

fathoms, and on some coasts there appear to be submerged terraces, but as a rule even these submarine slopes do not exceed the gradients found on our roads and railways, while the ocean-floor throughout the abyssal region may be regarded as consisting of vast gently undulating plains, interrupted here and there by elevations, some of which rise above the sea-surface to form oceanic islands, as, for instance, Bermuda in the Atlantic, Christmas Island in the Indian Ocean and many Pacific islands.

Sub-Oceanic Regions.—The mean depth of the ocean is estimated at 2080 fathoms (12,480 feet) and the mean height of the land at 375 fathoms (2250 feet). If we now suppose the higher portions of the continental elevations to be cut away and filled into the oceanic depressions, the depth of the ocean around the whole world would then be about 1700 fathoms (say 10,000 feet). This depth of 1700 fathoms has been called the *mean sphere level.* The region lying deeper than 1700 fathoms may be regarded as the great abyssal region or abyssal plain, covering an area exceeding 100 millions of square miles, or more than one-half of the earth's surface. Turning now to the continental shores, we find the continental shelf extending out from the shore-line to an average depth of 100

athoms, covering an area of about 10 millions of square miles; many deep submerged gullies which cross this shelf appear to be the continuations of existing river-channels, and are regarded as evidence that the continental shelf represents a former extension

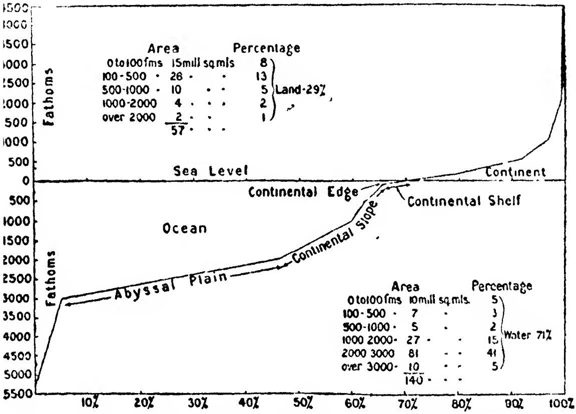

FIG 1.—Diagrammatic section showing the average contour of the lithosphere, based upon the percentages of the areas between the contour-lines above and below sea-level.

of the continents. The connecting continental slope, between the 100-fathoms line and the depth of the mean sphere level, covers an area of about 30 millions of square miles, or only three times that occupied by the continental shelf, although the interval of depth is 1600 fathoms as compared with 100 fathoms. The junction between the

continental slope and the continental shel has been called the continental edge, anc varies in depth and in distance from the shor in different parts of the world, though on ar average it may be put at about 100 fathom and about 50 miles off coasts bordering th great ocean basins (see Fig. 1, which is basec upon the percentages of the areas at definit intervals of depth below sea-level and o height above sea-level).

The foregoing paragraphs, which apply t general considerations concerning the deptl of the great ocean basins as a whole, ma be now supplemented by some informatior concerning each ocean, the enclosed sea connected therewith, and the submarin barriers separating them from the main ocean basin.

Depth of the Atlantic Ocean.—The dominan feature of the relief of the North Atlantic Ocear is a low submarine ridge, called the Dolphir Rise, running from north to south almos exactly in the central line of the basin, witl a series of deeps on either side. After a breal at the equator this central ridge, called th Challenger Ridge, is continued through th South Atlantic beyond lat. 50° S. Th entire ridge takes the form of an open S in accordance with the trend of the coasts and is covered by an average depth of abou

1700 fathoms. Towards the northern end the ridge widens out and the water shallows to the plateau on which the Azores are situated; farther north it merges into the "Telegraph Plateau," which extends across nearly the whole ocean from Ireland to Newfoundland.

Another remarkable feature of the North Atlantic is the series of submerged cones or oceanic shoals made known off the north-west coast of Africa between the Canary Islands and the Spanish peninsula, of which we may mention: the "Coral Patch" in lat. 34° 57′ N., long. 11° 57′ W., covered by 362 fathoms; the "Dacia Bank" in lat. 31° 9′ N., long. 13° 34′ W., covered by 47 fathoms; the "Seine Bank" in lat. 33° 47′ N., long. 14° 1′ W., covered by 81 fathoms; the "Concepcion Bank" in lat. 30° N. and long. 13° W., covered by 88 fathoms; the "Josephine Bank" in lat. 37° N., long. 14° W., covered by 32 fathoms; the "Gettysburg Bank" in lat. 36° N., long. 12° W., covered by 34 fathoms.

Precipitous slopes have been found round some of these banks: thus on the western edge of the "Coral Patch" the sinker distinctly struck bottom in 550 fathoms, tumbled over and continued to sink, struck in 620 fathoms, again tumbled over, and finally found a resting-place in 835 fathoms. When

it came up it had a large brownish-black streak where it had evidently struck obliquely on manganese peroxide. On the Dacia Bank a mark-buoy happened to be let go just on the edge of the bank in 175 fathoms. On trying to lift the moorings the buoy-rope carried away, and it was found to have been chafed through about 100 fathoms from the surface. The currents had evidently been rubbing it against the cliff during the two days that it was down.

The North Atlantic contains a relatively small number of islands, the principal of which are the British Isles, Newfoundland, the West Indies, the Azores, the Canaries, and the Cape Verde Islands.

The Arctic Ocean has a maximum depth of 2200 fathoms. It is cut off from the Norwegian Sea, in which the depth also exceeds 2000 fathoms, by the shallow water between the North Cape and Spitzbergen, and there are indications of a deeply submerged ridge also between Spitzbergen and Greenland. The Norwegian Sea is separated from the North Atlantic by what may be regarded as a continuous ridge running from Greenland to the British Islands plateau, of which Iceland and the Faroe Islands are emerged portions; that part of the ridge between Shetland and Faroe has been called the Wyville Thomson

Ridge, that between Faroe and Iceland the Faroe-Iceland Ridge, and that between Iceland and Greenland the Iceland-Greenland Ridge.

The North Sea is shallow, all less than 100 fathoms except in the Norwegian Gut or Norwegian Depression close to the Norwegian coast. Hudson Bay is also shallow, only a small portion exceeding 100 fathoms in depth. Davis Strait forms a shallow connection between the North Atlantic and Arctic, the depth in the centre of the narrowest part being 112 fathoms with deeper water both to the north and to the south.

The Mediterranean is cut off from the North Atlantic by a ridge at the Strait of Gibraltar, over which the greatest depth is only 175 fathoms, with steep slopes on either side. Depths exceeding 2000 fathoms occur in the Mediterranean between Sardinia and Italy and between Sicily and Greece, the maximum depth of 2400 fathoms being found off the strait between Crete and Greece. The Black Sea, which has a maximum depth of 1227 fathoms, is cut off from the Mediterranean by the shallow Sea of Marmora and the two connecting straits, the Bosphorus and the Dardanelles.

The Gulf of Mexico has a maximum depth of 2080 fathoms, and is connected with the

Atlantic by the Strait of Florida, in which the depth is less than 500 fathoms, and with the Caribbean Sea by the Yucatan Channel, in which the depth exceeds 1000 fathoms. The Caribbean Sea is divided into two deep basins by a ridge between Honduras and Jamaica, the maximum depth in the larger south-eastern basin being 2800 fathoms and in the smaller north-western basin 3428 fathoms (the Bartlett Deep); the passages between the various islands communicating with the North Atlantic are all less than 1000 fathoms in depth.

The South Atlantic differs from the North Atlantic in having no seas penetrating into the continents and remarkably few and small islands, like Ascension, Tristan da Cunha, St. Helena, and Trinidad. The dominant feature is the central ridge, with deep water on either side, which appears to be connected by a low ridge with the west coast of Africa.

The superficial area of the entire Atlantic Ocean, including the Arctic, Norwegian, Mediterranean, Caribbean Seas, etc., and extending southwards to the Antarctic Continent, is estimated at about 42 millions of square miles, divided according to depth as follows:—

Between 0 and 1000 fms.	about	11	million sq. m., or	26%
„ 1000 „ 2000 „	„	8	„ „	19%
„ 2000 „ 3000 „	„	20	„ „	48%
Over 3000 fathoms	„	3	„ „	7%
		42		100

Depth of the Indian Ocean.—The Indian Ocean differs from the other two great ocean basins in having no connection whatever with the Arctic, being shut in by land towards the north, and extending very little beyond the Tropic of Cancer. As regards depth it shows less diversity than the Atlantic and Pacific, two-thirds of its floor being covered by uniformly deep water over 2000 fathoms in depth. A large area less than 2000 fathoms surrounds Kerguelen, and there are five deep areas exceeding 3000 fathoms—four in its eastern portion and one in its western portion, to the south-east of Madagascar. The continental islands of Madagascar and Ceylon, and the groups of coral islands are found in the western and northern portions of the ocean, while the eastern portion is practically devoid of islands, the vast expanse of deep water being broken only by the Cocos group and Christmas Island. The Red Sea has a maximum depth of 1200 fathoms, and is cut off from the Indian Ocean by a barrier at the Strait of Bab-el-Mandeb, covered by less than

200 fathoms of water. The area of the Indian Ocean, extending southwards to the Antarctic continent, is estimated at 29 millions of square miles, distributed according to depth as follows:—

Between	0 and	1000 fms.	about	3	million	sq. m., or	11%
„	1000 „	2000 „	„	7	„	„	24%
„	2000 „	3000 „	„	17	„	„	59%
Over 3000 fathoms			„	2	„	„	6%
				29			100

Malay Archipelago.—The Malay Archipelago, separating the Indian Ocean from the Pacific, forms a remarkable geographical feature, the various islands enclosing a series of more or less landlocked seas cut off from the open ocean by barriers more or less deeply submerged. Java, Sumatra, Borneo and the lesser islands between them and the continent of Asia all rise from a great submerged bank, over which the depth nowhere exceeds 100 fathoms, while to the east of Borneo and Celebes the depths are much greater—in several places over 2500 fathoms. The limit of the shallow water, which runs from the east of Java to the east of Borneo, is called "Wallace's Line" after A. R. Wallace, who made a particular study of the distribution of land-animals on either side of the deep water separating the islands of Borneo, Java

and Bali on the one side from the islands of Celebes and Lombok on the other. The Arafura Sea is extremely shallow, with depths exceeding 100 fathoms only on its north-western border, where a depth of 1700 fathoms has been recorded, and in the Java Sea the depth is greater than 100 fathoms only on the eastern side, but at no place attains 1000 fathoms. In the southern portion of the China Sea the depth does not exceed 100 fathoms, but towards the north it increases, and between Luzon and the continental land there is a large area with depths over 2000 fathoms and a maximum depth of about 2500 fathoms. Over the barrier separating this sea from the main Pacific basin the depth exceeds 500 fathoms only in two narrow channels. The seas of the Malay Archipelago to the east of Borneo and Celebes form deeper basins. A large area of the floor of the Banda Sea lies below 2000 fathoms and includes the Weber Deep with a sounding in 3557 fathoms. Two other soundings have been recorded in depths exceeding 2700 fathoms, one in the northern part of the sea and the other in the south-west, off the island of Flores. The deepest channel of communication with the open ocean is the Molucca Passage, between Celebes and Halmahera, where the depth is well over 1000 fathoms. A large portion of

the Celebes Sea has depths over 2000 fathoms, with a maximum depth of 2795 fathoms, and the maximum depth of the Sulu Sea, just north of the Celebes Sea, is 2381 fathoms; the channels between the numerous islands cutting off these two seas from the Pacific are all shallow.

Enclosed Seas of the N.W. Pacific.—Another series of enclosed seas comparable with those of the Malay Archipelago runs along the whole of the western and northern borders of the Pacific to the shores of Alaska. Of these the Yellow Sea is the shallowest, the greater part of it having a depth less than 100 fathoms, with only a small area in the south where the depth exceeds 1000 fathoms, and where the maximum depth of about 1300 fathoms occurs. It is cut off from the open ocean by a line of islands, the Luchu Islands, stretching from Japan to Formosa, and the channels between these are generally between 100 and 500 fathoms deep. The Sea of Japan is to a great degree landlocked, the only communication with the Pacific being through the comparatively very narrow passages between the Japanese Islands and through the Korea Strait, in none of which does the depth exceed 100 fathoms. The greatest depth of the Sea of Japan is 1955 fathoms. The Sea of Okotsk is cut off from

the main ocean by the barrier of the Kurile Islands, the channels between which do not exceed 500 fathoms in depth. A considerable portion of this sea has depths over 1000 fathoms with a maximum depth of 1843 fathoms. The Bering Sea is very shallow towards the east, but a large part of the western portion has depths between 2000 and 2200 fathoms, and the greatest depth is 2936 fathoms. It is separated from the Pacific by the long chain of the Aleutian Islands, which are the emerged portions of a continuous volcanic ridge running from the peninsula of Kamchatka to that of Alaska. The depth over this ridge for the greater part of its length does not exceed 500 fathoms, but in the widest channel, that between Bering Island and Attu Island, the depth increases to 1996 fathoms.

Depth of the Pacific Ocean.—The eastern portion of the Pacific Ocean is characterised by great uniformity of depth, mostly exceeding 2000 fathoms, with a few volcanic islands and only a few small deeps. The Western Pacific is in complete contrast to the eastern portion, with numerous small volcanic and coral islands as well as continental islands like New Zealand, New Guinea and Japan, and with large areas less than 2000 fathoms in depth alternating with large deeps exceeding

3000 fathoms, and in some cases exceeding 4000 and even 5000 fathoms in depth. The contour-lines of depth are as a rule very irregular, the average depth varying from 1500 to 2500 fathoms, with innumerable volcanic ridges rising almost or quite to the surface, their summits for the most part crowned by coral reefs. The Coral Sea, lying between Australia, New Guinea, New Hebrides and New Caledonia, forms a deep oceanic basin exceeding 2500 fathoms in depth, but cut off from the general oceanic circulation by barriers covered by about 1300 fathoms of water, as proved by the "Challenger" temperature observations, which showed that at all depths beyond 1300 fathoms the temperature was uniform at 36° F. The region to the east of Australia is remarkable for the number of submarine elevations revealed by recent soundings, such as the "Britannia Hills," discovered in 1903 to the east of Southport, Queensland, covered by less than 300 fathoms, and the Balfour Shoal, described by the writer in 1897, covered by 836 fathoms of water. The Pacific Ocean extending northwards from the Antarctic Continent to Bering Strait is estimated to cover an area of about 69 millions of square miles, distributed according to depth as follows :—

Between 0 and 1000 fms.	about 7	million sq. m., or	10%
,, 1000 ,, 2000 ,,	,, 12	,, ,,	18%
,, 2000 ,, 3000 ,,	,, 45	,, ,,	65%
Over 3000 fathoms	,, 5	,, ,,	7%
	69		100

General Remarks.—When the figures given in the foregoing tables for the Atlantic, Indian and Pacific Oceans are compared with the figures for the whole ocean, the same general features may be recognised. The largest area is always that between 2000 and 3000 fathoms (48 per cent. in the Atlantic, 59 per cent. in the Indian, and 65 per cent. in the Pacific, as compared with 58 per cent. for the whole ocean), and the smallest that exceeding 3000 fathoms (6 or 7 per cent.). The Atlantic has the largest proportion of shallow water less than 1000 fathoms in depth (26 per cent., as compared with 10 and 11 per cent. for the Pacific and Indian Oceans respectively and 16 per cent. for the whole ocean), while the area between 1000 and 2000 fathoms varies from 18 per cent. in the Pacific to 24 per cent. in the Indian Ocean, the area for the Atlantic and for the whole ocean being 19 per cent. in each case.

The volume of dry land above sea-level has been estimated at 23 millions of cubic miles, the volume of the waters of the ocean at 324

millions of cubic miles, and the volume of the entire terrestrial sphere at 259,850 millions of cubic miles. The amount of material carried from the land into the ocean in suspension and in solution has been estimated at 3·7 cubic miles per annum; at this rate of degradation it would take about 6,340,000 years to transport the whole of the solid land down to the sea.

The volume of the ocean at the present day is to the volume of the whole sphere as 1 to 800, and, regarding the globe as covered by an ocean two miles in depth, the volume of that ocean would be to the volume of the sphere as 1 to 666.

CHAPTER III

THE WATERS OF THE OCEAN: SALINITY, GASES

All natural substances are soluble in water to some extent, be it ever so slight, so that absolutely pure water is never found in nature. Rain dissolves oxygen, nitrogen, carbonic acid, and other gases in its passage through the atmosphere. Carbonic acid increases the solvent power of rain-water, which dissolves different mineral matters out of the rocks of the continents and islands on which it falls, so that the amount and composition of the dissolved salts in the water of a river vary in accordance with the nature of the rocks of the country through which it flows. Thus the amount of salts in solution may range from 2 grains per gallon in a river flowing over granite rocks to more than 50 grains per gallon in a river traversing limestone rocks, but the average salinity of river-water is about 12 grains per gallon, or 0·18 part per thousand, as compared with 35 parts per thousand in average sea-water.

Scattered over the surface of the continents

there are numerous inland drainage areas in most of which are lakes. In these areas the precipitation of rain on the whole catchment basin is less than the evaporation; consequently there is no outflow from such a basin into the ocean. The higher lakes in a drainage area of this kind have an outflow into the lowest one and are fresh to the taste, like river-water, but the terminal lake is salt to the taste, like sea-water. The valley of the Jordan with the fresh-water Lake of Tiberias and the salt Dead Sea is an example. The greater part of the "run-off" from the land in the catchment basin of the Jordan ultimately finds its way into the Dead Sea, which may be compared to a huge evaporating basin; the surface layer of water is removed by evaporation under the action of winds and the sun's rays, the salts in solution being left behind. In this way in the course of time the Dead Sea has attained its great salinity. The concentration in a salt lake may go on till the lake completely dries up and only saline deposits are left behind.

In a similar manner the run-off from the whole of the land-surfaces of the globe carries dissolved salts into the ocean, but whereas the composition of the water in salt lakes is determined by the geological structure and climatic conditions of a comparatively small

area, the salts of the ocean are derived from all the land-surfaces and coasts of the globe.

In 1887 the writer gave a table of the average composition of river-water based upon the composition of nineteen European, Asiatic, and American rivers, and estimated the amount of saline matter carried annually into the ocean by rivers as nearly 5,000,000,000 tons. In 1910 F. W. Clarke made a similar calculation, based upon more recent and more extensive data, his result working out at about 2,700,000,000 tons, little more than half the earlier estimate.

We can form but a faint idea of the substances which were carried down from the atmosphere when the first precipitation of rain took place on our planet, or of the composition of the sea-salts in the primeval ocean. But the geological processes above indicated have apparently been in operation for millions of years. As a consequence the salinity of the ocean is probably continually increasing, but at such a very slow rate that the change cannot be detected by our present methods of analysis. Though the contributions of saline matter from rivers are large in themselves, they are relatively small compared with the vast accumulation of salts in solution in the ocean into which they are diffused.

The dissolved salts in river-water are

principally carbonates, which make up 57·7 per cent., sulphates 11·4 per cent., silicates 9·9 per cent., common salt only 2·2 per cent., with small quantities of other salts and organic matter.

The dissolved salts in sea-water are principally chlorides and sulphates of sodium, magnesium, potassium and calcium. Common salt makes up 77·8 per cent. (more than three-fourths of the whole), sulphates 10·8 per cent., but silicates do not exceed 0·004 per cent., and calcium carbonate forms only 0·345 per cent. This difference leads to the conclusion that sea-water is not merely a concentrated solution of river-water discharged from the land-surfaces throughout the geological past, but that changes have taken place due to chemical reactions between the various salts in solution and to the action of living organisms. In addition to the main constituents, sea-water holds in solution traces of nearly every known chemical element, but in such small proportions as to be negligible in quantitative chemical analyses; the presence of gold in sea-water has been repeatedly verified, and the possibility of its economic recovery suggested.

Average Composition of Sea-Salts.—The results of W. Dittmar's well-known analyses of 77 samples of sea-water collected by the

"Challenger" Expedition from all parts of the ocean and in all depths are given in the following table :—

Sodium chloride ...	27·213	parts per	1000.
Magnesium chloride ...	3·807	,,	,,
Magnesium sulphate ...	1·658	,,	,,
Calcium sulphate ...	1·260	,,	,,
Potassium sulphate ...	0·863	,,	,,
Calcium carbonate ...	0·123	,,	,,
Magnesium bromide ...	0·076	,,	,,
	35·000	,,	,,

Sea-Salts as Ions.—In the foregoing table the acids and bases are arbitrarily combined, but it is now known that the dissolved substances in sea-water are not accurately represented in this manner, inasmuch as they are present mainly as ions. The aggregate degree of ionic dissociation has been calculated from the freezing and boiling points of sea-water to be about 90 per cent. That is, only one-tenth of the total solids are present as salts pure and simple; these must comprise not only those named by Dittmar but all the possible combinations of bases with acids, among which calcium and magnesium sulphates will be relatively in largest proportion. The bulk of the solutes, however, consists of ions, and it would be more rational to write the composition of sea-water thus :—

CONSTITUENTS OF SEA-SALTS.

	Parts in 1000 of Water.	Percentage of Constituents.
Na	10·722 ...	30·64
Mg	1·316 ...	3·76
Ca	0·420 ...	1·20
K	0·382 ...	1·09
Cl	19·324 ...	55·21
SO_4	2·696 ...	7·70
CO_3	0·074 ...	0·21
Br	0·066 ...	0·19
	35·000 ...	100·00

Dittmar's item $CaCO_3$, which was presumably included in order to express the fact that there is on the whole an excess of bases over acids, is obviously incomplete as it stands. From the most recent measurements we gather that a 3 per cent. sodium chloride solution, in equilibrium as regards CO_2 tension with air (which holds good approximately for sea-water), dissolves at 77° F. about 0·07 part of calcium carbonate per thousand. Hence there cannot be as much as 0·123 part per thousand in sea-water. The surplus base should rather be regarded as a mixture of calcium and magnesium bicarbonates, existing in equilibrium with a certain amount of free CO_2, and of the products of their hydrolytic dissociation, viz. calcium and magnesium hydroxides. It is the two

latter which impart to sea-water its alkaline reaction.

Salts withdrawn from Sea-Water.—Carbonate-of-lime-secreting organisms withdraw large quantities of calcium carbonate from ocean-water to form shell and coral. Part of the material so withdrawn accumulates in coral reefs and in the pelagic deposits of moderate depths in the ocean, while part is redissolved after the death of the organisms, for the calcareous shells of many pelagic organisms never reach the greatest depths of the ocean, and only relatively few of the heavier pelagic shells reach the depths where red clay covers the bottom. In like manner silica is withdrawn from the ocean by organisms such as sponges, diatoms, and radiolarians, and may be again redissolved.

Potassium salts are withdrawn from ocean-water to combine with the silicates of alumina in argillaceous materials to form glauconite in the presence of organic matter. Potassium and iodine are selectively absorbed by certain species of seaweed ; indeed, until recent times seaweed was the chief industrial source of iodine.

When sea-water freezes many of the salts in solution are left behind in the brine, so that the salinity of the water from which the ice has been formed is increased, the ice

being richer in sulphates and the brine richer in chlorides.

Of the elements in solution in sea-water, sodium and chlorine seem to be the only ones that are scarcely withdrawn at all, apart from a small quantity deposited in shallow evaporating pans along the shores of the land-surfaces, and they may therefore have been uniformly on the increase since the beginning of geological time. This fact has been made use of in attempts to estimate the age of the earth, and J. Joly has calculated that to supply the total oceanic content of sodium by the discharge of rivers must have required a period of 90 to 100 millions of years.

Salinity of Sea-Water.—It has been found by numerous analyses that the composition of sea-water salts remains the same in all parts of the ocean and at all depths—that is to say, the actual ratio of bases and acids remains quite constant. The waters associated with the muds and oozes on the floor of the ocean and the waters of coasts, estuaries, and frozen seas, show slight variations in the individual constituent salts, but in the open ocean, away from contact with the shore and the bottom, the composition of the salts in sea-water remains practically constant, while the concentration varies.

The salinity or saltness of sea-water is

usually expressed as the amount of dissolved salts contained in 1000 parts of water. In average sea-water the dissolved solids amount to about 35 per thousand or 3·5 per cent. The term " salt " is applied not only to common salt (sodium chloride) but also to other similar compounds, like sodium sulphate, magnesium chloride, etc., which are present in sea-water, though common salt forms the principal constituent.

Methods of determining Salinity.—For determining the salinity of a given sample of sea-water various methods may be employed. The most direct method is to evaporate a known volume of water, drying and weighing the salts left in the residue, but in the drying process some of the chlorine is likely to be driven off as hydrochloric acid. Another method is to determine by means of the hydrometer or specific gravity bottle or pycnometer the relative density or specific gravity, that is the weight of a certain volume of sea-water at a given temperature compared with that of an equal volume of pure water at its temperature of maximum density, 39°·2 F. (a cubic centimetre of pure water at that temperature weighs one gram). Specific gravity varies with the amount of salts in solution, and depends also on the temperature, for sea-water expands and becomes lighter when heated and contracts

and becomes heavier when cooled, increasing in weight down to freezing-point (which varies with the salinity). Therefore, if the specific gravity is always determined at the same temperature, or if the determinations are reduced to one standard temperature, differences of specific gravity are due to differences of salinity alone. It is usual nowadays to express salinity in figures indicating the amount of salts in 1000 parts of sea-water, but at the time of the "Challenger" Expedition it was expressed, and still is by some observers, as specific gravity at 60° F. The following table gives the figures of specific gravity at 60° F. corresponding to various degrees of salinity:—

Salinity per thousand...	0·00	10·0	20·0	30·0
Specific gravity ...	1·0000	1·0058	1·0138	1·0220

Salinity per thousand...	32·5	35·0	37·5	40·0
Specific gravity ...	1·0240	1·0260	1·0280	1·0300

The most recent method of determining salinity is based on the fact that the ratio of the salts in solution to each other, and to the total salinity, is practically constant everywhere. It follows, therefore, that if we can determine the amount of one salt, we can calculate the total weight of all the salts present. The amount of chlorine in sea-water samples is easily and quickly determined by the method of chlorine titration.

In order to obtain uniformity in the determination of chlorine (halogens) by different workers, samples of "standard sea-water" are now issued by the International Commission for the Exploration of the Sea.

Another method of determining the salinity is based upon the fact that the refractivity of water, *i.e.*, the deflection undergone by a ray of monochromatic light when passing from air to water, stands in definite relation to the salinity, and still another method is based upon the measurement of the electrical conductivity or resistance of sea-water, but on the whole it may be said that the refractivity and conductivity methods of determining salinity have not come into general use.

Distribution of Salinity (see Plate III.).—The factors affecting the variation in the salinity of the surface waters of the ocean are precipitation and evaporation, the inflow of rivers, and the action of winds. In general a high salinity is found in those regions where the temperature and evaporation are high and the rainfall is small, and *vice versa*; for instance the highest salinity occurs in the eastern half of the Mediterranean and in the northern half of the Red Sea, where the salinity rises to over 39 per thousand—this being a region of great evaporation and small precipitation. The lowest salini[illegible]

34 per thousand), on the other hand, occur in the eastern part of the northern Indian Ocean, Bay of Bengal, Malay Archipelago, and western part of the China Sea, where the rainfall is extremely heavy and evaporation low. In the equatorial regions of each ocean there is a band of comparatively fresh water, and fresh zones surround the melting ice in the Arctic and Antarctic regions. Where rivers enter the ocean the lighter river-water tends to float on the surface, and its freshening influence may be detected at great distances from the land, and when much detrital matter is associated with this river-water the detritus in falling to the bottom carries with it some fresh water, and thus dilutes the underlying salt water to great depths. The effect of rivers is well shown in the case of the Baltic and Black Seas, where the salinity does not exceed 20 per thousand, and the Gulf of Guinea, where the salinity is less than 32 per thousand.

In permanent anticyclonic regions of the great oceans the salinity is very high (in the Sargasso Sea region of the North Atlantic it may attain 37·9 per thousand); out of these areas winds blow in all directions, and the drain caused thereby is compensated for by vast descending currents of very dry air, evaporation being necessarily very great.

In tropical regions the prevailing winds lrive the surface waters westwards to the astern shores of the continents, where acordingly there is a greater depth of warm ,nd saline water than elsewhere (except where he rainfall is abnormally heavy). On the ther hand, on the eastern sides of the oceans vhence the trade winds start on their course, .s off the west coasts of Africa and South merica, the warm saline surface water is lriven seaward, and the colder and fresher vater from below wells up to take its place.

In the North Atlantic the prevailing winds lo not blow home to the eastern coasts of the Jnited States, where the prevailing winds are outh-westerly, and consequently the higher alinities occur some distance seaward. To he south of lat. 40° N. the prevailing winds ecome more westerly as they advance in their asterly course, and gradually become northvesterly and then northerly on approaching he north-west coast of Africa, where they low home, and where the higher salinities re found close to the coast. In the South tlantic the south-east trade winds blow home o the South American coast between Cape t. Roque and the La Plata estuary, and it s off this coast that the higher salinities are ound.

The effect of the prevailing winds is also

very marked over the open ocean. In the intertropical Atlantic the line of lowest mean atmospheric pressure, towards which the prevailing winds and their attendant ocean currents flow, is situated at all seasons to the north of the equator, and therefore the surface currents of the South Atlantic, generated and maintained by the south-east trades, cross the equator, conveying a high temperature and a high salinity into a hemisphere other than that in which they originate. The remarkable salinity of the North Atlantic, markedly higher than that of any other ocean, has its explanation in the enormous overflowings into it by the surface currents of the South Atlantic, together with the equally remarkable contributions to the salinity at greater depths from the Mediterranean (see Fig. 2).

In the western portion of the Pacific, on the other hand, the line of lowest atmospheric pressure lies to the south of the equator for eight months of the year, and accordingly northerly winds with their accompanying ocean currents cross the equator to lat. 15° S., carrying a high salinity into the South Pacific. Thus the conditions of salinity in the Atlantic and Pacific are reversed, the highest salinity being found to the north of the equator in the Atlantic and to the south of it in the Pacific.

Generally speaking the salinity of ocean-water beneath the surface diminishes from the surface to a depth of 800 or 1000 fathoms and then increases to the bottom.

It has long been known that an interchange of water takes place between the Mediterranean and the North Atlantic at the Straits of Gibraltar—an upper current flowing into the Mediterranean from the Atlantic, and an undercurrent flowing out of the Mediterranean into the Atlantic—this interchange being due to the lowering of the level of the Mediterranean by excessive evaporation, and to the extraordinary difference in the salinities of the two seas. The submarine ridge at the strait is covered by about 200 fathoms of water, so that all direct communication between the two seas is limited to that depth. The outflowing warm dense saline water gradually sinks on entering the North Atlantic, and has a marked effect in raising the temperature and salinity of the deeper waters in that ocean.

Again, between the Black Sea and the Mediterranean there is a somewhat similar arrangement of currents, in this case due to the raising of the level of the Black Sea by excessive inflow from rivers and to the difference in salinity of the two seas, the intercommunication being complicated by the

interposition of the little Sea of Marmora between the two principal seas. The result is an outflowing surface current of brackish water through the Bosphorus into the Mediterranean, and a return undercurrent of dense saline Mediterranean water into the Black Sea (see Fig. 2). There is a similar interchange of water by currents at the surface and

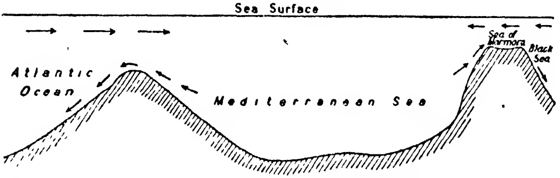

FIG. 2.—Diagrammatic section showing the inflowing and outflowing currents between the Mediterranean and the North Atlantic on the one hand, and the Mediterranean and Black Sea on the other.

below it between the Red Sea and the Indian Ocean through the Strait of Bab-el-Mandeb.

Gases in Sea-Water.—Atmospheric air is, roughly speaking, composed of four-fifths of nitrogen to one-fifth of oxygen, but oxygen is much more soluble in water than nitrogen, so that these two gases are not present in the same proportion when air is dissolved in water, the ratio of oxygen to nitrogen being much increased. Dry air free from extraneous substances contains about 21 per cent. of oxygen; air extracted from rain-water contains about 31 per cent. of oxygen, and air

from sea-water about 34 per cent. of oxygen, varying with the temperature and pressure.

The solubility of these gases is affected by the temperature of the water, the higher the temperature the smaller the quantity of gas absorbed, so that polar waters should, and actually do, contain more dissolved gases than tropical waters. The maximum amount of nitrogen and oxygen found by the "Challenger" was in the Southern Ocean towards the Antarctic, where the water contained 23·58 cubic centimetres per litre (or parts per thousand), and the minimum was in the tropical West Pacific, where the water contained only 11·85 cc. per litre of the two gases. In the former case oxygen made up 35·01 per cent. of the mixture, and in the latter 33·11 per cent. In the Norwegian Sea the percentage of oxygen in the mixture varies from 31·0 to 36·7, the average to the north of lat. 70° N. being 35·64, and to the south of lat. 70° N. 34·96; at the surface the mean percentage of oxygen is 35·3, diminishing beneath the surface to 32·5 at 300 fathoms, beyond which depth it remains nearly constant.

Except perhaps for an insignificant quantity of nitrogen derived from the decay of dead organisms, practically all the dissolved oxygen and nitrogen in the ocean has been absorbed

at the surface, and has been distributed by currents and diffusion even into the deepest parts. Nitrogen suffers no diminution, but the oxygen is continually being used up by marine organisms, in respiration during life, and in putrefaction after death; there is constant renewal of the oxygen at the surface, but were it not for the general circulation of its waters, however sluggish the motion, the proportion of oxygen in the depths of the ocean might be reduced ultimately to zero. Numerous analyses of deep-sea waters prove the presence of absorbed oxygen everywhere, so that in the open ocean not even at the greatest depths is there absolute stagnation. In some enclosed seas, like the Black Sea, where vertical circulation is almost nil, there is an absence of oxygen in deep water.

Carbonic acid is found as a free gas in very small quantities in sea-water, being more abundant in combination as carbonates and bicarbonates, so that though there may be 50 cc. per litre (or parts per thousand) of carbonic acid in sea-water, only a few tenths of a cc. is free gas in solution. The quantity varies considerably, depending largely upon the activity of plants and animals, and upon atmospheric conditions. When there is much carbonic acid in the air, as in regions near land and near active volcanoes, much is

absorbed by the sea. The tension of carbonic acid is usually greater over the land than over the sea, and the tension may be less in the air over the sea than in the sea itself, in which case carbonic acid would pass from the sea to the air. Thus according to circumstances there is an interchange of carbonic acid between the air and the sea, so that the sea has a regulating influence upon the amount of carbonic acid in the atmosphere. Beneath the surface the amount of free carbonic acid in the water has been shown in some places to increase with increase of depth.

Gases in the Black Sea.—The chemical conditions in the Black Sea, as compared with those in the open ocean, are peculiar, and may be briefly referred to. It has been calculated that the quantity of water introduced annually into the Black Sea from the Mediterranean by the undercurrent through the Bosphorus is only 1-2500th part of the volume of the Black Sea, so that, while the surface waters are being constantly renewed, the water of the deeper layers can be renewed only once in 2500 years or longer. Consequently the upper layers down to about 125 fathoms are normal in character, and contain a quantity of dissolved air sufficient to sustain life, but the oxygen of the deeper layers can

only be renewed by diffusion, and by the undercurrent from the Bosphorus, therefore much too slowly to maintain life. The amount of atmospheric gases diminishes with increase of depth, and at the same time sulphuretted hydrogen is formed and augments gradually on descending into deeper water, being equal to 33 cc. per litre (or parts per thousand) at a depth of 100 fathoms, 222 cc. per litre at 200 fathoms, 555 at 950 fathoms, and 655 at 1185 fathoms. Similarly sulphides appear and increase with the depth. The presence of sulphuretted hydrogen is attributed to the activity of bacteria; it partially combines with iron salts and partially penetrates into the water, its conservation being favoured by the poverty in oxygen of the deeper waters. Other chemical modifications in the deeper waters and deposits result, such as a relative diminution of sulphates and increase of carbonates, and the deposition of a powdery precipitate of calcium carbonate.

CHAPTER IV

THE WATERS OF THE OCEAN: TEMPERATURE

Properties of Fresh and Salt Water.—Before considering the distribution of temperature in the ocean it is desirable to recall some of the well-known properties of water. Although the significance of the term "temperature" has frequently been changed in scientific discussions, still the modern kinetic theory of heat appears to give a quite definite meaning to the word. The heat energy communicated to a material substance increases the kineti energy of translation of the molecules as whole, and it is this portion only of the heat energy which influences the temperature monatomic molecules alone retain all the heat they receive as heat "sensible" to the thermometer. In addition, heat energy may produce in all substances except monatomic gases, certain other kinds of motion, as for instance rotatory motion on the part of the molecules, or oscillatory motion on the part of the atoms within the molecule These molecular motions are spoken of as *path heat, spin*

heat and *wobble heat.* Such motions increase with a rise of temperature and decrease with a fall of temperature, but are distinct from changes of temperature. Again, changes of heat-content may condition changes of state of aggregation, of molecular or intramolecular complexity, etc., without necessarily affecting the temperature. Temperature is not the same thing as heat; it is not a quality of any particular body, but may be defined as that state or condition of matter on which depends its relative readiness to give or to receive heat.

Water has a greater capacity for heat—a higher specific heat—than any other liquid or solid. The specific heat of water is thirty times that of mercury, that is, the amount of heat required to raise the temperature of one pound of water through any interval of temperature is thirty times as much as that required to raise an equal mass of mercury through the same interval of temperature. The capacity of steam and ice for heat is only one-half that of water in the liquid state. For these reasons water is not warmed by the sun's rays to nearly the same extent as the land, nor does it cool so quickly when the sun's rays are absent. Another marked peculiarity of fresh water is that its maximum density point is at a temperature of 39·2° F. Above this temperature the volume

increases and the density diminishes with a rise of temperature, but also below this temperature the volume increases and the density diminishes with a *fall of temperature.* On freezing at 32° F., the ice, unlike most other substances, occupies a larger volume than an equal weight of water.

The specific heat of sea-water is less than that of fresh water, and sea-water is a better conductor of heat than fresh water. Again, the freezing point and the maximum density point of sea-water depend on the salinity. Water with a salinity of 35 per thousand freezes at 28° F., and the maximum density point is at the freezing point. It follows that any *sea-water* on being cooled will always sink through water of equal salinity, while *fresh water* at a temperature of 39. 2° F. will always sink through water having either a higher or a lower temperature.

In all questions dealing with the circulation of fresh water in lakes and of salt water in the ocean it is most important to bear these fundamental facts in mind. They account for the marked differences in the distribution of temperature in fresh-water lakes and in the ocean.

The methods and instruments employed in observing the temperature of ocean waters both at the surface and in great depths, have

been briefly described in Chapter I., so we may now proceed to a consideration of the distribution of temperature in the great oceans.

Distribution of Temperature.—Broadly speaking, the distribution of temperature at the surface is dependent on geographical position, the water being ice-cold at the poles and having a temperature of over 80° F. at the equator, but the position of the isothermal lines is much modified by prevailing winds, by the situation of land-masses, and by the position of the areas of barometric maxima and minima.

There is a nearly continuous broad band around the equatorial regions of the globe in which the mean annual surface temperature exceeds 80° F. To the north and south of this band the temperature decreases gradually towards the polar regions. A mean temperature exceeding 60° F. is found within the latitudes of 40° north and 40° south, except in the North Atlantic, where it extends beyond the parallel of 40° N. A mean temperature of 40° F. corresponds in the southern hemisphere with a latitude of about 55° S., while in the North Atlantic it extends to the north of lat. 70° N., beyond the North Cape. About 16 per cent. of the entire ocean surface has a mean temperature below 40° F.

In the Atlantic and eastern portion of the Pacific, areas of high surface temperature

(over 80° F.) lie to the north of the equator, owing to the fact that in these parts of the ocean the south-east trades protrude north of the equator as the simple result of the geographical distribution of atmospheric pressure there. Very different is it in the *western* division of the Pacific, where an area of high surface temperature (over 80°) extends east of Australia as far south as lat. 20° S., due to the circumstance that for eight months of the year the line of lowest barometric pressure is there to the south of the equator, and necessarily accompanied by northerly winds which propel into more southern regions the warmer surface waters of the western Pacific.

In the Indian Ocean a comparatively low surface temperature prevails over the north-western portion of the Arabian Sea, brought about by the prevailing north-westerly winds driving the warm surface water to the south-eastwards, and thus by upwelling off Cape Guardafui bringing the colder waters of lower depths to the surface. On the other hand, the prevailing winds in summer at the head of the Bay of Bengal are southerly and south-easterly, bringing from tropical regions the warm waters of the surface over the whole of the northern portion of this sea.

In the eastern part of the North Atlantic the prevailing southerly and south-westerly

winds carry to high latitudes the warm surface waters from the south, whereas in the western part near Nova Scotia the prevailing north-westerly winds in the cold months of the year carry the cold Arctic waters southward. The lowering of the surface temperature off the north-west coast of Africa is the direct result of the curving round of the prevailing winds in this part of the North Atlantic to north-west and north, thus transferring the surface waters from higher to lower latitudes. A lowering of the temperature from similar causes is seen off the west coasts of all the continents in trade wind latitudes, where the prevailing winds blow out from deserts, and from higher to lower latitudes (therefore from colder to warmer regions), and are consequently dry evaporating winds. On the other hand, a raising of the temperature is seen in these latitudes off the east coasts of the continents, where the prevailing winds pass from lower to higher latitudes (therefore from warmer to colder regions), and thus tend to precipitate their moisture in the form of warm rains.

Variation of Temperature.—The temperature of the surface waters of the ocean varies from day to day and from year to year at any one place, but to a much less extent than on land. The sun's heat is readily absorbed at the sur-

face and propagated downwards; but when the temperature of the water is raised, evaporation tends to check the rapidity of the rise; and when the temperature of the water is lowered, condensation of the water-vapour in the air resting upon the sea-surface checks the rapidity of the fall; and if the temperature becomes very low freezing sets in, again retarding the fall.

The *daily* variation of temperature in the air resting upon the dry land may in places be very large, as for instance in the desert regions of the tropics, where during the day the temperature of the air may rise to 125° F., while during the night the temperature may fall below the freezing point. This is in striking contrast to what holds good for the air resting upon the ocean, and in still greater contrast to what takes place in the actual surface waters of the sea. For example, during 126 days when the "Challenger" made observations in the North Atlantic Ocean the mean amplitude of the daily variation in the temperature of the air over the sea was 3·21° F. and on 76 of these days when the "Challenger" was near land the mean daily range was 4·38° F., indicating a larger range in the temperature of the air over the sea when near land than when out in the open ocean. During these same 126 days the mean daily range of

temperature in the surface waters of the North Atlantic was only 0·8° F. or one-fourth of that in the air resting upon them. An examination of the temperatures taken by the "Challenger" in other parts of the globe renders it highly probable that nowhere in the open ocean does the mean daily fluctuation of the temperature of the surface water amount to one degree ; hence the atmosphere over the ocean may be regarded as resting upon or blowing over a surface, the temperature of which is practically uniform at all hours of the day—a generalisation which is looked upon as a factor of prime importance in the study of the atmosphere and of ocean meteorology.

The *annual* variation of the temperature in the surface waters of the ocean at any one spot may exceed 50° F. in certain regions where the surface is occupied by cold waters coming from polar areas at one season, and by warm waters coming from tropical areas at another season ; but, on the other hand, there are very extensive regions both in tropical and polar waters where the range does not exceed a few degrees during the course of the year. A map showing the annual range of the surface temperature of the ocean (see Plate IV.) based upon the highest and lowest temperatures recorded within each two-degree square throughout the ocean basins, indicates

that the surface of the ocean may be divided into five zones, viz. a zone of small range and high temperature encircling the tropical regions, two zones of small range and low temperature encircling the two polar regions, and two intermediate zones of large range encircling the two temperate regions of the globe.

A range not exceeding 10° F. occurs in the Arctic Ocean, bordering the northern shores of Asia and America mostly within the Arctic Circle, and in the Antarctic Ocean as far north approximately as latitude 50° S. Throughout these two polar areas the observations indicate a range from 28° to about 50° F., though not exceeding ten degrees in any single two-degree square, and in certain squares being less than five degrees.

A range not exceeding 10° F., but with high temperature, occurs also in an almost continuous intertropical belt around the globe, broken only in the Pacific off the western shores of Central America; in the central portion of the South Pacific this belt extends as far south as lat. 30° S. The observations recorded throughout this belt vary from 70° to 90° F., though the range in any single two-degree square does not exceed 10° F. This practically embraces the coral-reef regions of the world.

Turning now to those portions of the sea-surface where the range exceeds 10°, we find that the area with a range of temperature between 10° and 20° F. is the most extensive, filling up the intervals between the inter-tropical belt and polar areas of small range just referred to, and enclosing in certain positions areas with a range greater than twenty degrees.

A range exceeding 20° F. occurs in the southern hemisphere south of the tropics in a band continuous across the South Atlantic and greater part of the South Indian Ocean with isolated areas off South Australia, New Zealand and South America; in the northern hemisphere extensive areas cross the North Pacific and North Atlantic, extending into the Mediterranean and Baltic.

A range exceeding 30° F. is found in two large areas, one in the north-west Atlantic, off the east coast of North America between lat. 30° N. and 50° N., the other in the north-west Pacific, off the east coast of Asia between lat. 22° N. and 56° N., with smaller areas in the Mediterranean and Black Sea, in the Baltic and North Sea, at the heads of the Red Sea and Persian Gulf, off the mouth of the Rio de la Plata, and south of the Cape of Good Hope and Madagascar on the parallel of 40° S.

A range exceeding 40° F. occurs in the north-

western portions of the Atlantic and Pacific Oceans, in which positions the greatest variation of temperature in the surface waters of the globe is found, and in the north-western part of the Black Sea and eastern part of the Mediterranean near Cyprus.

A range of surface temperature exceeding 50° F. is found only in the north-west Atlantic and north-west Pacific. The North Atlantic area is much the larger, extending off the North American coast, to the south of Nova Scotia, seawards almost to longitude 50° W.; the greatest recorded range within a single two-degree square is 52° (from 28° to 80° F.), while the extreme range within the area is 56° (from 27° to 83° F.). The North Pacific area lies off the coast of Asia in the Sea of Japan, in about the same latitude as the Atlantic area (40° N.); the greatest recorded range within a single two-degree square is 52·7° (from 28·8° to 81·5° F.), and the extreme range within the area is nearly 55° (from 28·8° to 83·7° F.).

From an oceanographical point of view the areas having a large range of surface temperature are extremely important in their effect on organisms, and they will be further referred to in later chapters.

The lowest recorded temperature at the surface of the sea is 26° F. observed in the

North Atlantic eastward of Nova Scotia, and the highest reading in the open ocean is 90° F. recorded in the tropical Pacific both north and south of the equator, while readings of 94° and 96° F. have been recorded in the Red Sea and Persian Gulf respectively. The greatest known range of temperature in the surface waters throughout the whole world is thus 70° F. (from 26° to 96°), being very small when compared with the extreme variation of the temperature over the land-surfaces of the globe, which may exceed 220° F.

Temperature Conditions beneath the Surface.—Let us now turn to the distribution of temperature in the depths of the ocean. Except in the icy regions of the far north and far south, and in some other exceptional positions, the temperature of ocean water decreases from the surface downwards to the bottom. In tropical regions, where the water at the surface is warm (75° or 80° F.), the temperature decreases at first very rapidly, the warm water forming a relatively thin film, then more and more slowly towards the bottom in deep water. This is the general rule as to the distribution of temperature in the open ocean, but an exception is found in the case of partially enclosed seas, like those fringing the western border of the Pacific Ocean, which are cut off from the general oceanic circulation by

barriers more or less deeply submerged, the position and height of the barriers determining the deep-water temperature conditions within the seas. Thus, supposing a barrier covered by 500 fathoms of water to separate one of these seas from the open ocean, the temperature would be found to decrease in like manner,

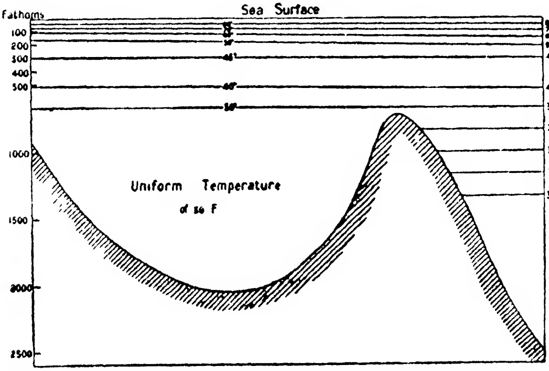

FIG. 3.—Diagrammatic section across the barrier separating the Celebes Sea from the North Pacific, showing distribution of temperature.

both within the sea and in the open ocean outside, down to 500 fathoms; but deeper than 500 fathoms in the open ocean the temperature would continue to decrease downwards to the bottom, whereas in the enclosed sea no further decrease would be observed beyond 500 fathoms. In other words, the deep basin of the enclosed sea is occupied by water which is believed to have flowed over the barrier from

the open ocean, carrying with it a temperature corresponding to that at the top of the barrier (see Fig. 3). Such is the case in the Sulu Sea, the Banda Sea, etc.

The deep water of the enclosed basin may take a temperature determined by the mean winter air-temperature of the region, and this deep water then flows as an undercurrent over the barrier into the open ocean, as in the case of the Mediterranean and the Red Sea.

Another variation in the distribution of temperature occasioned by barriers is found in the case of a polar basin cut off from the general oceanic circulation, such as the Norwegian Sea, cut off from the Atlantic by the Wyville Thomson Ridge, the summit of which is covered by water 200 to 250 fathoms in depth. Here the warm Atlantic water flows northwards, and the cold water found on the northern side of the ridge is this Atlantic water which has been cooled in the Norwegian Sea, has sunk towards the bottom, and then flowed south as far as the Wyville Thomson Ridge in depths greater than 250 fathoms. The result is that the temperature on both sides of the ridge decreases from surface to bottom, but to the north of the ridge the decrease downwards from the level of the ridge is much greater than to the south (see Fig. 4), so that a differ-

ence of 15° may be found in the bottom temperatures on the two sides of the ridge: 30° F. on the polar side and 45° F. on the Atlantic side.

The seasonal variation in the temperature

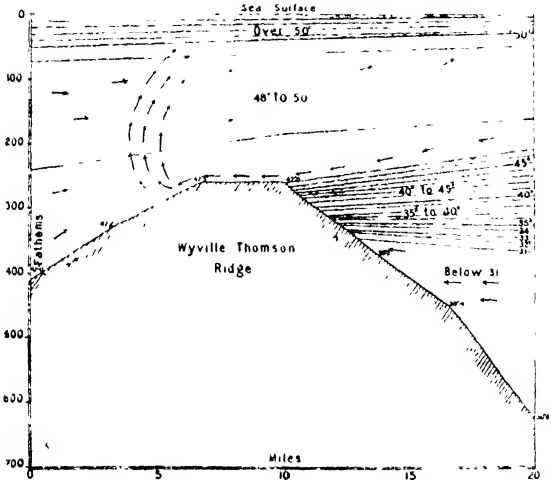

FIG. 4.—Diagrammatic section across the Wyville Thomson Ridge, showing distribution of temperature and currents.

of ocean water becomes less and less on passing downwards below the surface, and seems to disappear at a depth of about 100 fathoms, beyond which depth temperature readings are looked upon as good annual means. Nevertheless, some observations recorded by R. E. Peake in the North Atlantic would seem to

indicate that even in deep water there may be a slight seasonal or other variation, and this is supported to some extent by temperature observations taken by the "Michael Sars" in 1910 in the same positions where observations had been taken by the "Challenger" in 1873.

To show the gradual decrease of temperature with increase of depth in the open ocean we give here a table of mean temperatures for the whole ocean, as calculated from all the observations in all latitudes at the specified depths, from the "Challenger" Report on Oceanic Circulation :—

Depth.	Mean Temperature.	Depth.	Mean Temperature.
100 fathoms	... 60·7° F.	900 fathoms	... 36·8° F.
200 ,,	... 50·1° F.	1000 ,,	... 36·5° F.
300 ,,	... 44·7° F.	1100 ,,	... 36·1° F.
400 ,,	... 41·8° F.	1200 ,,	... 35·8° F.
500 ,,	... 40·1° F.	1300 ,,	... 35·6° F.
600 ,,	... 39·0° F.	1400 ,,	... 35·4° F.
700 ,,	... 38·1° F.	1500 ,,	.. 35·3° F.
800 ,,	... 37·3° F.	2200 ,,	... 35·2° F.

At a depth of 100 *fathoms* between lat. 30° N. and 30° S., the temperature in the western portions of the ocean basins is very much higher than in the eastern portions. This is brought about by the ocean currents setting in to the west, originated and maintained by the north-east and south-east trade-winds, which drive the warm surface waters before

them towards the eastern coasts of the continents.

The North and South Atlantic are in striking contrast at this depth, the North Atlantic being much warmer than the South Atlantic. In the South Atlantic the area with a temperature above the mean for this depth is mall as compared with the similar area in orth Atlantic, and the highest tempera- outh Atlantic is only 63° F., North Atlantic there is a large temperature exceeding 63° F., ses two small areas each with a re rising to 70° F. This contrast is the fact that in the Atlantic the region of calms between the north and south trades is at all seasons north of the equator, reaching its northern limit in lat. 13° N. in July, and its southern limit in lat. 2° N. in January. Hence the south-east trades penetrate at all seasons into the northern hemisphere, driving before them the warm surface waters of the South Atlantic. Thus vast quantities of warm surface water are transferred bodily to the North Atlantic, resulting in these two ocean basins presenting as regards temperature the strongest contrasts to each other, not only at 100 fathoms but at all depths down to the bottom. The mean annual position of the region of equatorial calms

coincides with the path of least barometric pressure in that region, the position of which gives to the North and South Atlantic their distinctive contrasted features.

The distribution of temperature in the Pacific at a depth of 100 fathoms is precisely the reverse of what obtains in the Atlantic, the South Pacific being much warmer th the North Pacific. In the North Pac highest temperature (70° F.) two very small areas, where Pacific the area with a temperatu is large, and encloses another ex where the temperature exceeds 72° F due to the fact that the line of lowest ba metric pressure lies to the south of the equator from long. 160° E. to 130° W. For eight months of the year this state of things substantially holds good, culminating in December, January, and February, when barometric pressure is very low in Australia, and when the north-east trades and ocean currents of the western Pacific extend into the South Pacific to about lat. 15° S.

A feature of the temperature at 100 fathoms in all the oceans is a pronounced increase in the eastern *equatorial* region of each ocean on nearing the continents: thus, in the Pacific about the Galapagos Islands, the temperature is 62° F., or twelve degrees higher than in the

same latitude some distance to the westward; in the Atlantic the temperature rises to 59° F. in the Gulf of Guinea, or six degrees warmer than it is to the westward. In the Indian Ocean the temperature rises to 60° F. in the Bay of Bengal, or four degrees higher than it is to the southward and westward. This -nounced increase of temperature is ascribed causes: (1) the monsoonal deflection vinds, for some distance out heir course to westward, so as rds and in upon the heated land inents, carrying the warm waters the coast, this cause operating strongest during those months when atmospheric pressure is lower in the interior than on the coast; (2) the back water or counter equatorial current to the east, which sets in particularly in the eastern division of the region of calms between the north and south trades.

It is noteworthy that in the equatorial region of the eastern Pacific to the north of the equator a very low temperature (50° F.) is found at a depth of 100 fathoms, whereas at the same depth to the south of the equator, at a distance of only eighteen degrees of latitude, the temperature is very high (72° F.). This striking example is typical of the distribution of temperature over the greater

portion of the intertropical part of the Pacific, the difference in temperature being small at the surface, but this difference increases downwards to about 100 fathoms, where it may exceed 20° F., then decreases again down to about 200 fathoms.

Similar areas of low temperature occur in the equatorial part of the Indian Ocean
the south of Ceylon, and in the co
part of the Atlantic to the
Guinea, the Atlantic area lyir
of the equator, while the India
areas are situated to the north of t
that is to say, on that side of the
where the warm waters of the surface, owing to the diminished density, are not diffused or conveyed so quickly downwards to greater depths.

The expanse of low temperature at 100 fathoms in the Pacific is bounded on each side by those tracts of the ocean where the trade winds are strongest, and these trades impel to the westward warm surface currents, which, by friction, extend to a considerable depth in the ocean. The result is that the currents of the trades proper take a large portion of their supply from the sea directly underlying the calm intervening region between the north and south trades; hence there necessarily sets in an upwelling. These

areas of low temperature in all the oceans are found some distance to westward of the continents, apparently proportional to the breadth of the ocean.

At a depth of 300 *fathoms* the higher temperature of the North Atlantic as compared with the South Atlantic is even more pronounced than at lesser depths ; the highest temperature South Atlantic (48° F.) covers a very hereas in the North Atlantic re covers about half the ocean, wo areas within which the temses to fully 60° F., in the more ne in fact it rises to 63° F., or fifteen ... higher than anything found in the South Atlantic. The highest temperature in any other ocean at this depth is 53° F., or ten degrees lower than that of the North Atlantic, thus emphatically distinguishing this ocean from all other oceans in this respect. The Pacific Ocean has temperatures above the mean uninterruptedly through eighty degrees of latitude in its western division, and through forty degrees of latitude in its eastern division, the highest temperatures being 51° F., about ten degrees of latitude south of Japan, and 50° F. the same distance north of New Zealand. A low temperature (under 45° F.) still prevails in mid-ocean immediately south of the equator. The Indian Ocean at this depth

is above the mean, the lowest temperature (45° F.) occurring in the sea between Australia and Java, and the highest (over 53° F.) in the open ocean to the east and south of Madagascar, and in the Red Sea and the entrance thereto.

At a depth of 500 *fathoms* marked changes in the distribution of temperature over the Atlantic are observable as compared lesser depths: nearly the whole
Atlantic is below the mean, w
the whole of the North Atla
the mean, the highest temperatu
being found immediately to the
Gibraltar as the effect of the under
from the Mediterranean. In the North Pacific no region of high temperature is to be seen, but in the South Pacific there is a well-marked area between Australia and New Zealand, where the temperature rises to 44° F. The temperature conditions in the Indian Ocean are similar to those at 300 fathoms, the highest temperature in the open ocean being 46° F. to the south-east of Madagascar.

At a depth of 700 *fathoms* the high temperature in the North Atlantic from the Straits of Gibraltar (where the temperature is 51° F.) oceanwards is still the striking feature of the temperature. The highest temperature in the Pacific is 40° F, to the

north of New Zealand and near the Galapagos Islands, and in the Indian Ocean 44° F. in the western portion of the Arabian Sea

At a depth of 900 *fathoms* the highest temperature (42° F.) is still in the North Atlantic to the west of Gibraltar, from which the temperature steadily falls westwards in the same manner as at lesser depths, but only
extent of two degrees. In the South
peratures are relatively higher,
ific there is a tendency towards
emperature more than in any of
ceans.

depth of 1500 *fathoms* the highest
atures are: in the North Atlantic 38° F., in the South Atlantic 37·5° F., in the Indian Ocean 37° F., in the North Pacific 36·5° F., and in the South Pacific 36° F. The North and South Atlantic have nearly the same temperature, while the Indian Ocean is now the coldest ocean, a large portion being below the mean, due evidently to an underflow from the Antarctic.

At a depth of 2200 *fathoms* the temperature of the North Atlantic is everywhere above the mean, observations at fifty-five stations giving an average of 36·4° F., or 1·2° above the mean. Over the whole of the South Atlantic to the south of latitude 10° S. the temperature is under the mean—slightly on

the eastern side but very greatly on the south-western side; at three stations to the east of Buenos Ayres the temperature is only 32·6° F., which is the lowest yet observed in any part of the ocean at this depth. In the Indian Ocean the temperature is everywhere below the mean, observations at twenty stations giving an average of 34·4° F., or 0·8° below the mean. A large portion of
Pacific has a temperature below th
this depth, the lowest being 33·2
to the south of Kamchatka, bu
the cold area of the Pacific gen
deficiency below the mean is small,
on the whole it may be said that the temp-
ture of the Pacific at 2200 fathoms closely approximates to the mean for all the oceans at this depth, viz. 35·2° F.

Bottom Temperature.—The surface of the ocean may be regarded as a level plain, whereas the floor of the ocean is an undulating plain, and therefore a map showing the *bottom* temperature, *i.e.*, the temperature of the water in actual contact with the sea-floor, is very different from one showing the *surface* temperature. At the surface of the earth, both on land and at sea, the lines of equal temperature run more or less parallel to the equator, that is to say, in an east and west direction, whereas at the bottom of the ocean

they run on the whole north and south, following the general trend of the continents. The warmer waters covering the ocean's bed form narrow bands in the shallow waters along the continental shores and around the oceanic islands outside the polar regions, separated from each other by wide stretches representing the colder waters of the deep sea. bottom temperature below 30° F. is the ice-bound regions of the Ant- ctic Oceans, extending in the southward of the Faroe Islands. temperature between 30° and found over an area covering nearly whole of the sea-floor in the Antarctic and great Southern Oceans, extending throughout nearly the whole of the Indian Ocean, and sending offshoots into the Atlantic and Pacific. A bottom temperature between 35° and 40° F. occurs over nearly the whole of the North Atlantic, and a very large part of the Pacific. Observations show that in depths beyond 2000 fathoms the average temperature over the floor of the North Atlantic is about two degrees above the average temperature at the bottom of the South Atlantic and Indian Oceans, while the temperature over the bed of the Pacific is intermediate between these. A bottom temperature between 40° and 50° F. occurs principally in the comparatively shallow

waters of tropical regions, but extends sometimes a considerable distance outside the tropics, as, for instance, in the north-east Atlantic where it runs along the coast of Norway. A bottom temperature between 50° and 60° F. occupies a narrow strip along the shores of continents and around islands within and near the tropical regions, and fills the Mediterranean, while a bottom tem ture exceeding 60° F. is almost wh to pics, filling up the Red S in east end of the Mediterr bottom temperature may reach depths beyond 100 fathoms around t of coral islands in the Pacific, in the Indian seas, and in the Red Sea.

General Remarks.—It has already been stated that only 16 per cent. of the entire sea-surface of the globe has a mean temperature below 40° F., whereas of the entire sea-floor 92 per cent. is overlaid by water having a temperature under 40° F. It has also been stated that the warm surface waters of the tropical regions form a comparatively thin stratum, and therefore the great mass of ocean water must be relatively cold. A rough estimation of the proportion of the entire bulk of water in the ocean having a temperature below 40° F. gave over 80 per cent., so that less than 20 per cent. has a temperature

exceeding 40° F. The mean temperature of all the observations taken at a depth of 500 fathoms works out at about 40° F., so that on the average all the water in the ocean deeper than 500 fathoms may be said to have a temperature below 40° F.; this would be equal to about 87 per cent. of the entire ocean.

The most striking fact revealed by deep-sea
vations of temperature in all latitudes is
w temperature of the ocean at great
ver 2000 fathoms, even under
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emperature is but a very little way
freezing point of fresh water, and
nge, except in a few restricted regions, does not exceed 2° F. The ooze dredged from the ocean-floor in the tropics is so cold that it cannot be handled without discomfort. The lowest deep-sea temperatures are found in those parts of the ocean which lie in the southern hemisphere, and on the whole higher temperatures are encountered on receding from the Antarctic regions; the lower deep-sea temperatures extend farther to the north from the Southern Ocean over those depths of the sea which appear to have uninterrupted communication with the south, that is to say, are not cut off by any intervening submarine ridges separating them from the cold waters of the Antarctic.

There can be no doubt that these very low deep-sea temperatures have their origin very largely in the Southern or Antarctic Ocean, the ice-cold waters of which are slowly propagated northwards, the rate of propagation being so slight as to be regarded rather as a slow creep than as a distinctly recognisable movement of the water. At the same time it is evident that the increase of t perature from the bottom of the oc surfac , due to the descent c waters the surface carrying their higher temperature and sal. to the bottom.

Temperature Conditions in the Black Sea. By way of contrast with the temperature conditions in the open ocean it is interesting to glance at the state of matters in an enclosed sea, like the Black Sea, which is the receptacle for a large body of dense water introduced from the Mediterranean into its deeper parts, where it lies in an almost stagnant condition, covered by a superficial layer of comparatively fresh water. Vertical circulation is limited to the superficial layer, and this leads to peculiar physical conditions, and to the almost total absence of life in the deeper water, where there is an abundant formation of sulphuretted hydrogen.

In July, 1890, the temperature at the

surface varied from 71·4° to 78·6° F., falling rapidly beneath the surface until the coldest water in the whole sea, varying from 43·7° to 45·7° F., was reached in depths of 25 to 50 fathoms, this minimum temperature being generally found nearer the surface in the central parts of the sea than elsewhere. At a depth of 100 fathoms the temperature
d from 46·2° to 48·2° F., the mean
F., while at a depth of 200 fathoms
as 48·0° F., the variation not
alf a degree. At still greater
temperature was nearly uniform
F., with a maximum of 48·7° F., in
e deepest part in 1200 fathoms; therefore the bottom water has a temperature about four degrees higher than the minimum temperature at 50 fathoms.

CHAPTER V

WATERS OF THE OCEAN: COMPRESSIBILITY, PRESSURE, COLOUR, VISCOSITY, PENE' TION OF LIGHT, TIDES, WAVE'

In the preceding chapters we
with the salinity and temperature
in the ocean, and it is now desirable
few words about some of the other physica.
characteristics and movements of ocean water which must be taken into consideration in the discussion of oceanic circulation and of marine biological problems.

Compressibility of Water.—In 1661 some academicians at Florence, wishing to test the compressibility of water, filled a thin gold globe with that liquid, and, after hermetically sealing it, exposed it to pressure with the view of altering its form, well knowing that any alteration in form of a sphere must be accompanied by a diminution in volume. The consequence was that the water forced its way through the pores of the gold and stood on the outside of the globe like dew.

This experiment has since been repeated with globes made of other metals with like results, and for a long time all liquids were regarded as being absolutely incompressible, but subsequent researches have shown that liquids are really slightly compressible. Some authors say the compression is proportional to the pressure up to a pressure of 65 atmospheres, but P. G. Tait and J. Y. Buchanan have shown that compressibility decreases slightly with increase of pressure. Water is compressible by about one twenty-thousandth of its bulk under the pressure of one atmosphere. At 4000 fathoms the pressure would reduce the bulk of 10,500 cubic feet of surface water to about 10,000 cubic feet, and Tait calculated that, if gravity should suddenly cease to act, the surface of the oceans would immediately rise 200 feet.

Pressure at Different Depths.—The pressure of the atmosphere at sea-level may be taken as 15 lbs. to the square inch, which is equal to the weight of 30 inches of mercury. Thirty-four feet of fresh water and 33 feet of salt water are equal to 30 inches of mercury, so that at 33 feet of depth in the sea the pressure would be two atmospheres including the true atmosphere, at a depth of 66 feet three atmospheres, at 99 feet four atmospheres, or 60 lbs. to the square inch, and so on, as shown in the

following table, in which the true atmosphere is not taken into account :—

TABLE OF PRESSURE.

Depth.		Pressure per square inch.	
	Atmospheres.	Lbs.	Tons.
33 feet ...	1	15	—
66 " ...	2	30	—
99 " ...	3	45	—
100 fathoms ...	18	270	—
500 " ...	90	1350	—
1000 " ...	180	2700	1·2
2000 " ...	360	5400	2·4
3000 " ...	540	8100	3·6
4000 " ...	720	10,800	4·8
5000 " ...	900	13,500	6·0[1]
5348 " ...	960	14,400	6·4

[1] Tait's expression of one ton per 1000 fathoms would mean 5 tons at 5000 fathoms instead of 6 tons as above.

Effect of Pressure.—There is a widespread view among many people that under great pressure water becomes much denser and may attain something of the consistency of treacle, that ships and men, when they sink in the sea, " reach their level," but do not reach the bottom. The Sargasso Sea has been represented as a great whirlpool, in which men and ships float about at all depths. Within the past year the writer has often been asked if the " Titanic " really reached the bottom in a depth of three miles. During the " Challenger " Expedition, after a funeral

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more? Another que.
really did go to the botto.
like on reaching bottom at fo.

A living rabbit was on one .
down to over 500 fathoms on a .
body came up very little altered to all a.
ance, the bones were all intact, and the lu.
were the only viscera that seemed to be affected by the pressure. Even at 3000 fathoms a human body would be little altered in outward appearance.

The "Titanic" is probably now lying on the bottom in a very little altered condition: only those parts of the structure would be burst inwards ("imploded") into which water could not enter rapidly enough to equalise the pressure on the two sides, say, of an iron plate. As the vessel sank deeper and deeper, the corks in all the wine and beer bottles would be driven in if not quite full, and ultimately every hermetically closed chamber or recess would be imploded.

The fact is that anything that will sink to the bottom of a tumbler of water will practically sink to the bottom of the deepest ocean.

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floor of the
.. icate calcareous
.. anisms which once
. aters.
during the "Challenger"
. wo thermometers sent to the
. 75 fathoms collapsed owing to
. ressure. J. Y. Buchanan then took
. lass tubes of different calibres, sealed at
. ends, wrapped them in a cloth, and enclosed them in a cylindrical copper case having the ends pierced with holes in order to permit the free passage of water. The case was sent down to 2800 fathoms, and when it came up again it looked as if it had been struck in the middle with a hammer. On being opened the cloth was found to be full of what looked like snow but was in reality finely comminuted glass; the two wider glass tubes had collapsed, while the narrow one was still intact.

The experiment was repeated later, only one glass tube being used and sent down to a depth of 3000 fathoms. The copper case was again indented at that portion occupied inside by the sealed glass tube, which was reduced to powder. It seems that the sealed glass tube, while sinking, had held out long

against
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powder. The collap
complete that the wate
rush in through the holes
copper cylinder and thus fill t
caused by the collapse of the gla
had instead crushed in the copper
thus brought about equilibrium. The
cess, which is exactly the reverse of an expl
sion, is called an "implosion."

During the "Michael Sars" Expedition in 1910 a large number of glass floats wrapped in cloth were sent down to great depths inside a large zinc cylinder: these were all "imploded" and reduced to fine white powder, while the cylinder was indented opposite each one of the imploded floats. Some pieces of wood which had been sent down to a great depth attached to a "Challenger" dredge, on being brought up again sank like bricks in a tub of water: all the little cells of the wood had been "imploded" in deep water.

Effect of Release of Pressure.—When water is exposed to great pressure its volume is slightly diminished, and, some heat being liberated, the temperature of the liquid rises. Conversely the volume of a liquid released

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n is drawn
temperature.
nple is drawn up
le from a depth of,
ne temperature of the
, the amount of cooling
ne temperature of the water.
sample brought up from a depth of
ms in the cold Norwegian Sea is cooled
. while being hauled up, but a sample
m the same depth in the warm Mediterranean
is cooled 0·3° F.

A curious effect of the release of great pressure in the depths of the ocean is sometimes seen in the case of fishes living in very deep water. If for any reason they rise much above the depth at which they are adapted to live, the decrease of pressure causes their swimming bladders to expand, and their specific gravity is greatly reduced. Up to a certain limit the muscles of their bodies can counteract the tendency to float upwards, but beyond that they are helpless, and go on "tumbling upwards" to the surface, being gradually killed by the distension of their organs as the pressure is relieved.

The effect of the great pressure in the ocean on its inhabitants may be observed experimentally by means of an ingenious apparatus

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gradually diminish…
recover their normal fu…
movement, when the int…
their bodies have had time to …
rium with the pressure of the
medium. When the sudden in…
pressure exceeds a certain limit, death …
through the rupture of the cells of the tiss…
which are soaked with water.

Colour of Sea-Water.—W. Spring made many experiments on the colour of fresh water, and found that ordinary distilled water was of a greenish colour, which he believed to be due to impurities remaining in the water after distillation; samples of water rendered absolutely pure had a beautiful clear blue colour. In the open ocean the water is generally of a bluish colour, and near land and in estuaries green or yellowish green; within the thirtieth parallels north and south of the equator the colour is a brilliant ultramarine, and to the south of lat. 30° S. it changes rapidly to a deep indigo, which continues as far as the Antarctic Circle, where it changes to olive-green. The blue colour is attributed to the rays of light being unequally absorbed by water, blue rays

. rays.
materials
in the neigh-
water is usually
ascribed to calcium
while the green colour
e far south is due to the
oms and other minute plants.
The viscosity or internal friction
er is important from its bearing upon
ating powers of organisms and other
gical phenomena. Variations of viscos-
ty are almost entirely dependent on variations of temperature, for within the common limits of salinity (30 to 35 per thousand) variations in viscosity due to differences in salinity may be entirely neglected. Viscosity diminishes with increase of temperature, as shown in the following table :—

Temperature	Viscosity. Pure water at 32° F. = 100	
	Salinity 30 per 1000	Salinity 35 per 1000
32° F.	102	103
41° F.	87	88
50° F.	75	76
59° F.	66	66
68° F.	58	59
77° F.	52	53
86° F.	47	47

It will be seen that sea-water at 77° F. is only half as viscous as the same water at 32° F., that is to say, the same body would sink twice as rapidly in water at a temperature of 77° as in water at 32°. Sea-water at a high temperature may be said to be relatively " thin " as compared with the same water at a low temperature. The bearing of this on the development of suspension-organs by floating organisms in cold and warm waters will be referred to later.

Penetration of Light.—When the sun's rays strike the surface of the sea, some of them are reflected and the others penetrate into the water, being gradually absorbed at different depths according to the wave-length of the ray and the clearness of the water. The dark heat rays are absorbed most quickly—in the uppermost layers—whilst the light rays penetrate deeper, the blue rays penetrating the deepest of all.

Many observations have been made to determine the intensity of light at different depths by means of photographic plates. In the Mediterranean the effect of light has been traced down to depths of 260 fathoms off the Riviera and 300 fathoms off Capri. The latest observations, made during bright sunshine in June, 1910, in the Sargasso Sea by Helland-Hansen during the " Michael Sars " Expedi-

tion, showed that at 550 fathoms there was still sufficient light to affect a sensitive plate after exposure for 80 minutes. Another plate was exposed at a depth of about 900 fathoms for two hours, but showed no effect whatever. It is thus seen that the limit at which light-penetration in the open ocean can be detected is somewhere between 600 and 900 fathoms, that is, considerably deeper than was previously supposed. Further observations with filters for rays of different colour showed that at a depth of 275 fathoms many blue rays were present but hardly any red ones, whilst at 55 fathoms all the light-rays were present, though there were fewer of the red than of the others. In the seas of higher latitudes and nearer land the light-rays do not penetrate so deep, largely owing to the suspended particles in the water.

Waves.—Though having an apparent forward movement, wave motion in the open sea does not involve a massive movement of the water, the wave-form only moving on, while the water-particles describe curves and are supposed to come to rest approximately at the points whence they started. A strong wind may blow forward the top of a wave, making it break and giving it a motion independent of the true wave motion, and even should the wave not break the surface water slips along

to some extent before the wind. On advancing from the open sea into water so shallow that the wave motion is sensible down to the bottom, the wave is retarded at the bottom, its velocity and length are diminished, its height increased, and the top of the wave pitches forward as surf. Thus in strong winds and in shallow water there is a forward movement of some of the water in a wave, which is then called a wave of translation. On striking a shore obliquely waves may give rise to a shore current. Violent storms give rise to waves which run far from their place of origin, diminishing in height but retaining their length and velocity if unobstructed, and constituting a swell or "ground-swell." The sea-surface in the open ocean is probably seldom quite smooth, there being generally a "ground-swell" due to storms in different places, sometimes at great distances.

The height and length of waves, and the depth to which their effect is felt, depend on the depth and extent or "fetch" of the ocean in which they occur. The greatest waves are believed to occur in the North Atlantic and in the great Southern Ocean, where waves 560 feet in length and 50 to 60 feet in height are recorded. Off the north coasts of Scotland fine particles of sand are believed to be moved about on the bottom at a depth

of nearly 200 fathoms during heavy gales from the south-west. Some abnormal waves which have been observed in the ocean are known to be due to earthquakes and volcanic eruptions.

Tides.—The term tide is applied to the periodical rising and falling of the water of the ocean caused by the attraction of the sun and moon. Periodical alternations in the direction of the wind, and periodical variations in atmospheric pressure, may give rise to alternations in the level of the sea, but true tides are attributed to astronomical causes. It is supposed that the attraction of the sun and moon may affect not only the waters of the ocean but also the solid crust of the earth, producing an alternating change in its shape, but so small as to be difficult of detection.

Any one living at the seaside must have observed the gradual advance and retirement of the sea about twice in the 24 hours, or to be more exact, twice in 24 hours 50 minutes, the average interval between two successive high waters being 12 hours 25 minutes. The time of high-water thus changes from day to day, and is evidently related to the position of the moon, which passes the meridian on an average 50 minutes later on each succeeding day. The height to which the water rises varies also from day to day,

the range from high-water to low-water being greatest about the time of full moon and new moon, when the tides are called "spring-tides," and least about the time of the moon's first and third quarters, when the tides are called "neap-tides." The tide-generating effect of the moon is more than double that of the sun, because of the very much greater distance of the sun, in spite of its greater mass. When the sun and moon are both on the same side of the earth, as at new moon, and when they are diametrically opposed to each other, as at full moon, their tide-generating effects are additive, but when they are at right angles to each other, as at half moon, waxing and waning, the effects are subtractive, so that the spring-tides have a range three times greater than the neap-tides.

It is usual to regard the sun and moon as producing a tidal wave which develops freely in the Southern Ocean, where a zone of water encircles the earth. This wave has a very great length with high-water at the crest and low-water in the trough. On passing the opening between Africa and South America it gives rise to a lateral wave, moving from south to north through the whole Atlantic, producing tidal effects in Northern Europe and America. Besides this wave there is formed another tide-wave in the Atlantic

following the movement of the sun and moon from east to west. The whole phenomenon is further complicated by the discovery in the ocean of standing and boundary-waves, similar to the " seiches " which have long been known in the fresh-water lakes of Switzerland and Scotland. As will be seen in succeeding paragraphs attempts have been made to explain tidal phenomena from the analogy of seiches.

The rise and fall of the tide is accompanied by currents, especially where obstructions are encountered, and the height to which the tide may rise is determined by the configuration of the land ; the high tides of the Severn and of the Bay of Fundy may be mentioned in this connection. Tidal currents prevent the formation of muddy deposits on the top of the Wyville Thomson Ridge at a depth of 250 fathoms. J. Y. Buchanan measured tidal currents on the Dacia Bank, and R. N. Wolfenden discovered similar tidal currents on the Gettysburg Bank. More recently the " Michael Sars " Expedition of 1910 measured tidal currents in the open ocean down to a depth of 400 fathoms. It was found that the currents at 274 fathoms ran in the opposite direction to that of the upper layers, which again approached that of the currents at much greater depths. At certain moments the currents appear to be arranged in the form of a spiral

staircase, the whole system turning in clockwise direction from top to bottom.

Seiches—Long-period oscillations in the ocean have now been recognised, but have not yet been carefully observed. As in lakes they may be of two kinds: the ordinary seiche and the temperature seiche:—

(1) A seiche is a standing oscillation of

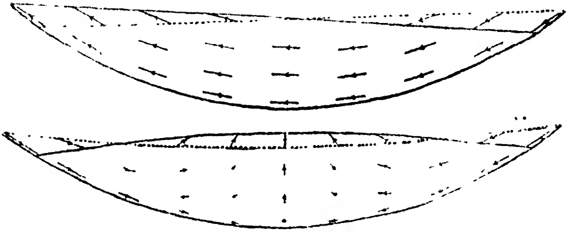

FIG. 5.—Diagrams of uninodal (upper) and binodal (lower) seiches (the arrows indicate the direction and amplitude of the movements of the water-particles, and the dotted and continuous lines indicate the position of the surface at opposite phases)

the whole body of water in a defined basin. The simplest form of oscillation is where there is no vertical motion at a central point in a lake, and where the vertical motions at the two ends of the lake are of opposite phase. The point where there is no vertical motion is called a node. The surface of the lake at the extremes of the oscillation may be represented by the plain and dotted lines in Fig. 5. We may have two nodes, in which case the phase of the motions at the two ends is the same,

but opposite to the phase of the motion at the centre of the lake, and so forth for any number of nodes. Some basins are better tuned for seiches than others, and in one lake the commonest oscillation may have two or more nodes, in another the commonest oscillation may be of the fundamental type with one node. The period of the oscillation depends on the shape of the basin. Roughly speaking, it varies directly as the length of the basin, and inversely as the square root of the depth. One effect of a seiche is to cause a to-and-fro motion of all the water particles in the basin. At a node this to-and-fro motion is purely horizontal, and at the ends it is mainly vertical. Where the wave-length of the oscillation is large compared with the depth of the basin, as is the case in all lakes of any size, then the component of horizontal motion at any point at the bottom of the lake is the same as at the surface vertically above. At every part of the bottom the motion is tangential to the slope of the bottom. We can, therefore, by observing the current produced at the surface by a seiche, find out the current which will be caused at the bottom of the lake. The velocity of these currents may be calculated when the shape of the lake is known.

These oscillations in fresh-water lakes have

their analogy in the ocean, and F. A. Forel explained the currents in the Strait of Euripus at Chalcis by assuming a seiche in the Talanti Channel. Japanese observers have shown that seiches exist in all well-defined bays in the ocean, having a node at the mouth of the bay, and a belly at the head. The period of these seiches is also susceptible of calculation, given the shape of the bay.

Many tidal phenomena could probably be explained in this way. Certainly the small embroideries on the records of tide gauges in bays or enclosed areas of the ocean are frequently due to seiches. But much longer oscillations may possibly admit of similar explanations; the supposition that stations where the range of the tide is very small are near a node would explain many things. But the problem regarded as one of standing waves in limited oceans caused by lunar attraction is much complicated by variations in the intensity of the lunar attraction at any one point on the earth's surface, and by the rotation of the earth. Neglecting all such complications, we see that the period of a seiche in the Atlantic from Spain to Florida might be about twenty-four hours, and a binodal seiche about twelve hours. Tidal records have not yet been examined carefully with this special object in view.

(2) The existence of temperature oscillations in the ocean and in lakes has lately attracted much attention. In fresh-water lakes in autumn there forms a *Sprungschicht*, or "discontinuity layer," through which the rate of fall of temperature is much greater than at other depths. The lake then behaves as if it consisted of two layers of liquid of different density which do not mix; the difference in density is produced by the difference in temperature between the surface and the bottom waters. There is also a marked difference in the viscosity of the two layers. The effect of wind blowing along the surface of a lake when the temperature distribution is of this nature is to accumulate the warm surface water at the lee end of the lake. The discontinuity layer is deeper at the lee than at the windward end, but when the wind ceases the discontinuity layer swings back through the normal horizontal position, and oscillations of the lower layer of cold water commence. No motion is observable at the surface of the lake, but the oscillations of the discontinuity layer are often of great amplitude. These oscillations have a node at the centre of the lake, but binodal or plurinodal oscillations are also possible. The period of these oscillations or temperature seiches is determined by two things:

(1) the shape of the lake-basin, and (2) the temperature distribution. The smaller the difference between the temperature of the upper and bottom water the longer will be the period. Mathematical formulæ have been obtained which take account of varying breadth, depth, and temperature distribution, from which the period of the temperature oscillations can be calculated.

Such oscillations are also possible in the ocean wherever there is a sharp difference in density some distance beneath the surface. The difficulty of recording them, however, is so great that there are no observations which definitely show the existence of long-period oscillations in the ocean. The period of these oscillations must frequently be days or weeks, and continuous observations in one position over a lengthy period would be necessary to demonstrate their existence.

Otto Pettersson did observe an oscillation in the Skaggerak with a period of fourteen days, and, on the assumption that this was a temperature seiche analogous to the seiches observed in bays by the Japanese, E. M. Wedderburn calculated the period for the Skaggerak, which was found to be fourteen days. It is possible therefore that what Pettersson observed was a temperature seiche

Wherever we have two liquids of different

density superimposed, whether the difference of density be due to salinity or temperature, we may have slow travelling waves occurring at the surface of separation. Observations in the ocean show the existence of such progressive waves, but again there is the difficulty that we must have observations taken continuously for a lengthy period in the same position before we can be sure of the nature of these waves. Their period also depends on the difference of density of the liquids above and below the surface of separation, and the smaller this difference the slower will be the velocity of the waves, and for a given disturbing force the greater the amplitude. These waves may be caused by currents in either the bottom or the surface waters, just as waves on the surface of the sea are caused by wind currents in the atmosphere.

Dead Water.—When a layer of comparatively fresh water several feet in thickness rests on a salt layer, a passing ship gives rise to a boundary-wave, such as above referred to, which may retard or even stop the ship, so that it lies in what is called " dead water."

CHAPTER VI

OCEANIC CIRCULATION

In preceding chapters it has been pointed out that the density of sea-water varies with both the salinity and the temperature. In all questions concerning oceanic circulation the density of the water as dependent on salinity and temperature must be taken into careful consideration.

Theoretically we would expect the densest water to be found at the bottom of the ocean, and this is what actually occurs, as is shown in the following table giving the mean density for the whole ocean at different depths :—

	Mean Density.
Surface	1·0252
100 fathoms	1·0261
200 ,, ...	1·0268
300 ,, ...	1·0271
400 ,, ...	1·0273
800 ,, ...	1·0276
1500 ,, to the bottom ...	1·0279
2000 ,, ,, ,, ...	1·0280

This increase of the mean density with depth is almost wholly occasioned by the

decrease of temperature down to at least 800 fathoms, but at depths of 1500 fathoms and deeper the increasing density is due both to the slowly diminishing temperature and to the actual increase of the salinity at these great depths. It cannot be doubted that the increased salinity at these greater depths, where the differences of temperature with depth are very small, indicates that the deep waters over the bed of the ocean are derived chiefly from the Antarctic and sub-Antarctic regions, and in a less degree from the Arctic and sub-Arctic regions of the globe.

When we consider the density *in situ* in the different oceans, it becomes evident that density has a most important effect on ocean circulation. The mere fact that sea-water is not equally heavy everywhere must be regarded as one of the chief causes of ocean currents. Water being so remarkably mobile, small differences in density result in sensible motion.

Density at various Depths.—At a depth of 100 fathoms there is a marked difference in the density of the water in the North and South Pacific, the density being much higher in the western South Pacific than in the North Pacific. In the eastern South Pacific towards the South American coast the density is low, and here in consequence of the south-east

trade-winds upwelling is to be expected. The North Atlantic is remarkable for its high density at 100 fathoms—higher than that observed in any other part of the ocean. In the South Atlantic off the South American coast the density is high, falling on proceeding eastwards towards the mid-Atlantic ridge, while still farther east density is much lower, evidently in relation to the upwelling towards the African coast.

At a depth of 200 fathoms density is much higher in the North than in the South Atlantic, and higher in the South than in the North Pacific, but in the Pacific the observations approximate to each other from lat. 30° N. to 40° S., the mean being much below that of the North Atlantic.

At a depth of 400 fathoms density is considerably higher in the North than in the South Atlantic, being determined by the descent of the warm salt water of the upper layers to greater depths in the North than in the South Atlantic. In the south-west Pacific density is higher than elsewhere throughout the Pacific, for a similar reason.

At 500 fathoms the density of the water is much higher in the North Atlantic than any elsewhere observed, as also at 600 fathoms, especially to the west of the Canary Islands, pointing unmistakably to the undercurrent

issuing from the Mediterranean as the source of the remarkably high temperature and salinity overspreading the North Atlantic. At 700 and at 800 fathoms the same influence is traceable in the high densities recorded to the east of the Azores and to the west of Gibraltar.

Prevailing Winds.—The prevailing winds of the globe in their direct and indirect effects taken in conjunction with the configuration of the land-masses are, however, the most powerful agents in originating, giving direction to, and maintaining the circulation of oceanic waters. They undoubtedly originate and maintain the surface currents of the ocean, and the influence of these currents is, through friction, felt to a depth of evidently several hundred fathoms. In intertropical regions the prevailing trade-winds drive the surface currents westwards to the eastern shores of the continents, where accordingly a greater depth of warm water is found occupying the upper layers of the ocean than elsewhere. Except where the rainfall is abnormally heavy this water not only is very warm but has acquired from evaporation a salinity much higher than the general average of the ocean. These areas of high surface temperature and high salinity are found represented at all depths down to the bottom, with a tendency

to an extension of the areas with increase of depth. It follows that the great mass of the ocean intermediate between the upper layers and the bottom largely exhibits the effect of vertical movements. On the other hand, on the eastern sides of the oceans, whence the trade-winds start on their course, there is an upwelling of the colder water of the greater depths towards the surface. These cold areas of a lower surface temperature and salinity are also continued down to the bottom, with a tendency to an expansion of the areas with descent. The ice-cold and nearly ice-cold water which occupies the bottom of the ocean in all latitudes necessitates a constant supply of water of a very low temperature from the surface of the Southern and Antarctic Oceans, and in a less degree from the sub-Arctic Ocean. This slow-moving descent of cold water, and its slow creep in the deeper layers and along the bottom of all parts of the ocean, are effected on the one hand by the reduction in intertropical regions of the surface waters by evaporation, and by the extratropical prevailing winds blowing the surface waters polewards, and on the other hand by the greater densities of the ocean in high latitudes and the " head " of water accumulated there by the prevailing south-westerly winds of the northern hemisphere and the prevailing

north-westerly winds of the southern hemisphere.

Subsidiary causes powerfully influencing oceanic circulation are :—(1) abnormally heavy rainfall such as occurs in the West Pacific, (2) undercurrents of high temperature and density from the Mediterranean and Red Sea, (3) the causes leading to the extensive upwelling seen in the eastern Pacific and in analogous positions in the Atlantic and Indian Oceans, which are closely connected with the supply of a portion of the water of the great surface currents from the deeper waters of these oceans, and (4) the intertropical position of the line of lowest mean barometric pressure, resulting in a temperature much higher in the North Atlantic than in the South Atlantic and much higher in the South-west Pacific than in the North Pacific.

The winds are in turn dependent upon differences of atmospheric pressure, blowing from areas of high pressure towards areas of low pressure, and it seems desirable here to direct attention to this aspect of the subject. Over the equator the air, which contains much water-vapour, is heated, therefore expands and ascends, so that a belt of permanently low pressure occurs over this area all the year round. In the temperate regions both north and south of the tropics there are large

areas of high barometric pressure (anti-cyclonic areas) situated over the oceans practically all the year round, out of which winds blow in all directions towards the surrounding regions where atmospheric pressure is lower; for instance, the trade-winds blow into the equatorial low pressure area from both sides.

In these anticyclonic regions of the oceans calms and light variable winds prevail, and this necessarily implies vast accessions of air setting towards them as upper aerial currents, thence slowly descending to the surface of the sea to take the place of the air passing out as surface winds; the result is that in these regions the air is relatively very dry, evaporation is very great, and the specific gravity of the surface water is high. Not only is the barometric pressure in these anticyclonic areas usually very high, but the oscillations of the barometer are very small. Thus the "Challenger" observations in the anti-cyclonic areas of the great oceans showed in the South Pacific in lat. 35° S. a difference between the morning maximum and the afternoon minimum of only 0·036 inch; in the North Pacific in lat. 36° N. this difference was only 0·025 inch, or less than a third of what occurs near the equator; in the South Atlantic the difference was also 0·025 inch, while in the North Atlantic it was only

0·014 inch. The air filling the central portions of the anticyclones is relatively immobile, and probably contains fewer dust particles than elsewhere; it will therefore be less cooled by nocturnal radiation and less heated by solar radiation, and the change of the aqueous vapour from the gaseous to the liquid state and *vice versa* will also be less than elsewhere.

The effect of the earth's rotation on a body moving on its surface is to cause it to deviate towards the right in the northern hemisphere and towards the left in the southern hemisphere. The winds are therefore deflected, the trade-winds in the northern hemisphere blowing equatorwards from the north-east, and in the southern hemisphere from the south-east, while the winds blowing polewards from the anticyclonic areas of temperate regions become westerly winds in both the northern and southern hemispheres.

The alternate heating and cooling of the continental masses in summer and winter result in the formation of regions of low pressure in summer and of high pressure in winter over the interior of great continents. In the northern summer over the interior of Asia the pressure is low (cyclonic) and winds blow in from the surrounding oceans; the south-east trade-wind of the Indian Ocean is thus deflected and becomes a south-west wind

called the south-west monsoon. In winter the pressure is high (anticyclonic) over the same area in the interior of Asia, and winds blow out from the land, strengthening the north-east trade-wind, which is called the north-east monsoon. The permanent winds are thus influenced and their direction altered in the northern part of the Indian Ocean, and similar effects though not so marked are found in the neighbourhood of all continental masses. In the great Southern Ocean the expanse of water is practically unbroken by continental land, and the westerly winds blow regularly all the year round, like the trade-winds; the belt between lat. 40° and 50° S. is called by sailors the "roaring forties" because of the strength and constancy of these "brave west winds," the barometer being permanently low throughout this region, while all observations indicate that a permanent anticyclone rests upon the Antarctic continent to the south.

In the anticyclonic areas the movement of the air in the northern hemisphere is in the direction of the movement of the hands of a clock (clockwise), and in the southern hemisphere in the opposite (counter-clockwise) direction.

Surface Currents.—The general movements of the surface waters correspond with the

general movements of the overlying atmosphere just referred to, the separate currents represented on the accompanying map (Plate V.) forming part of the general system.

In the Atlantic the *South Equatorial Current* flows westwards across the ocean before the south-east trade-wind, until it divides into two branches off Cape St. Roque in Brazil, one flowing southwards along the South American coast as the *Brazil Current*, the other flowing north-westwards to enter the Caribbean Sea and to contribute towards the formation of the *Gulf Stream.* When the *Brazil Current* comes under the influence of the westerly winds the water is swept eastwards across the South Atlantic, partly merging into the *Benguela Current* and flowing northwards along the African west coast, thus completing the rotatory circulation of the South Atlantic. The *Benguela Current* is also indirectly due to the south-east trade-winds, which drive the surface water before them along the West African coast, thus causing upwelling of the colder water from beneath to replace that driven forward at the surface. The *North Equatorial Current* flows westwards across the ocean before the north-east trade-wind until on reaching the Windward Islands it is driven partly into the Caribbean Sea and partly round the outside of the West Indies towards the

North American coast. Between the *North* and *South Equatorial Currents* there is a *Counter Equatorial Current* flowing eastwards into the Gulf of Guinea. The flow of water into the Caribbean Sea from the two equatorial currents and thence into the Gulf of Mexico raises the level of the water in that Gulf considerably above the level of the open ocean, and the water issues through the Strait of Florida as a warm saline current, known as the *Gulf Stream.* It is joined by the waters skirting the West Indies and flows along the United States coast, always growing wider, shallower, cooler and less saline, until about the latitude of Cape Hatteras it curves in a north-easterly direction, and after encountering the cold *Labrador Current* from the north in the vicinity of the Newfoundland Banks, crosses the Atlantic, merging gradually into the *North Atlantic Drift.* On approaching the coasts of Europe this surface drift is divided, one branch owing to the pull of the winds around the North Atlantic anticyclonic area flowing in a south-easterly and then southerly direction as the *Canaries Current,* thus completing the North Atlantic "water-whirl," the other branch continuing in a north-easterly direction past the British Isles, across the Wyville Thomson Ridge, and along the coast of Norway. Cold Arctic currents flow

southward (1) along the east coast of Greenland (the *East Greenland Current*), and thus a subsidiary "whirl" is produced in the Norwegian Sea, and (2) along the coasts of Labrador and Newfoundland (the *Labrador Current*). In the South Atlantic a counterpart of the *Labrador Current* of the North Atlantic is found in the *Falkland Current*, a northerly-flowing branch of the great easterly *Antarctic Drift* of the Southern Ocean.

The general surface circulation in the Pacific is similar to that in the Atlantic, but the numerous groups of islands introduce greater complexity. The rotatory circulation of the North Pacific round the high pressure area is formed by the *North Equatorial Current*, the Kuro Sivo or *Japan Stream* (corresponding to the Atlantic Gulf Stream), the *North Pacific Drift*, and the *Californian* and *Mexican Currents*. A cold Arctic current (the *Kamchatka Current*) flows southward from Bering Strait until it meets the Japan Stream. Crossing the *Counter Equatorial Current*, we have the South Pacific circulatory movement formed by the *South Equatorial Current* flowing westward, the *East Australian Current* (corresponding to the Brazil Current of the Atlantic), and the easterly *Antarctic Drift*, which sends a branch between Tasmania and New Zealand (corresponding to

the Atlantic Falkland Current), and another branch to supplement the *Peru* or *Humboldt Current* (corresponding to the Benguela Current in the Atlantic).

In the Indian Ocean the circulatory movement is complete only in the southern portion, where it is formed by the *South Equatorial Current* flowing westward, the *Mozambique Current* (corresponding to the Brazil Current of the Atlantic), the easterly *Antarctic Drift*, and the *West Australian Current* (corresponding to the Benguela Current of the Atlantic). In the northern portion of the Indian Ocean during the north-east monsoon there is a *North Equatorial Current* flowing westward and a *Counter Equatorial Current* flowing eastward, but in summer the south-west monsoon obliterates these currents.

Vertical Circulation.—After having thus dealt with the horizontal circulation in the surface waters of the ocean, let us turn now to a consideration of the circulation in the deeper waters of the great ocean basins Into the Southern Ocean the Brazil Current, Mozambique Current, and East Australian Current carry inconceivably enormous volumes of warm saline waters from lower latitudes, which in their passage southwards come under the influence of the strong westerly or north-westerly winds of the "roaring

forties," and by and by necessarily become colder, hence denser, and sink to greater depths. Both salinity and temperature contribute to this effect, and the sinking waters carry with them the atmospheric gases to aerate the deeper waters of the ocean. Towards the south these waters on sinking are drawn farther southward and become overlaid by the cold and less saline waters diluted from the melted snow and icebergs of the Antarctic regions. They are also slowly drawn equatorwards to supply the place of the warm surface currents driven south by the winds. From the enormous quantities of warm water they impel before them into the Southern Ocean, these strong north-westerly winds may be regarded as playing the most conspicuous part of all the prevailing winds in the circulation of the waters of the ocean. A striking feature of the waters of the Southern Ocean is the interdigitation of currents differing widely from each other both in temperature and salinity, the colder of these currents having their origin, doubtless, in the Antarctic regions. Another important part played by the vast currents of warm and salt water is to mitigate most materially the cold of the Antarctic region, particularly at great depths, and thus to restrict the ice-clad area to its present limits.

In the North Atlantic and in a less degree

in the North Pacific we have a similar vertical circulation due to the same causes as in the great Southern Ocean, but owing to the less extent of the water surface, and the restricted communication with the Arctic Ocean, the effect upon the deeper waters of the ocean basins is not so pronounced.

The vertical movements of ocean water are brought about (1) by the pull of winds on the

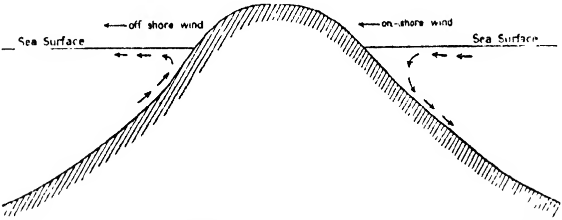

FIG. 6.—Diagram showing the effect of wind on lee and windward shores.

surface water resulting in upwelling, (2) by differences in salinity between different layers produced by precipitation and evaporation, and (3) by differences of density due to changes of temperature.

Upwelling is most marked whenever the winds blow from the land towards the open ocean; the deeper water, having usually a lower salinity and a lower temperature than the water driven before the wind, is thus brought to the surface. On the other hand the water

driven against a lee shore is banked up and tends to descend (see Fig. 6).

When precipitation is abundant as in equatorial regions the fresh water at the surface tends to retard vertical circulation. On the other hand when winds blow from colder to warmer regions, or when dry desert winds blow across water, as in the case of the Red Sea and Mediterranean, they are capable of taking up much water-vapour from the surface layers, which thus become more saline, consequently denser, and tend to sink through the subjacent layers.

In these ways water descends and ascends in the ocean, and in the descent the atmospheric gases absorbed at the surface are carried down to great depths, and changes in the temperature and salinity are brought about.

The foregoing remarks may be illustrated by reference to the accompanying map showing the surface density in the ocean (Plate VI.), from which it will be noticed that the density is greatest in high latitudes both of the northern and southern hemispheres, due principally to the low temperature, but where there is a mixture with salt water from the tropical areas the density is more pronounced than elsewhere. In tropical regions there is a broad continuous band around the globe in which the density is less than 1·024, enclosing

an extensive area of the Indian and Pacific Oceans with a density less than 1·023. In temperate regions the density increases, until beyond the fortieth parallels north and south the density usually exceeds 1·026, with well marked maxima in the great Southern Ocean and in the North Atlantic and Norwegian Sea, where densities exceeding 1·027 prevail over large areas, extending in the south as far as

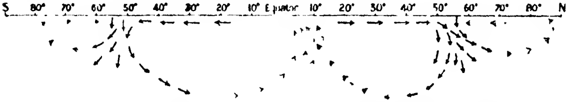

FIG 7.—Diagram showing the general circulation of the waters of the Atlantic Ocean (continuous arrows indicate relatively warm water and dotted arrows relatively cold water).

lat. 58° S., and in the north as far as lat. 78° N. in the neighbourhood of Spitzbergen. It is especially in these areas of high density that the relatively warm saline waters from intertropical regions on being cooled sink down beneath the surface, returning equatorwards to a large extent as a slowly-creeping deep-seated undercurrent, and being drawn polewards to a less extent to replace the water carried away by the polar surface currents, as shown in the accompanying section, which is constructed diagrammatically to illustrate the general system of circulation in the Atlantic (see Fig. 7). It may also be pointed out that the waters which leave the surface in

these high latitudes, owing to their low temperature, carry down a greater quantity of the atmospheric gases than would waters of a higher temperature, and thus aerate more efficiently the whole of the deeper layers of the ocean.

CHAPTER VII

LIFE IN THE OCEAN: PLANTS

THE term biosphere is now used by naturalists to designate that mantle of living matter which clothes the globe wherever the atmosphere, the hydrosphere and the lithosphere are in contact and intermingle. On the dry land living beings do not rise very high above, or penetrate very deep below, the surface, but in the ocean it is different. Life is present everywhere throughout the mass of ocean waters, from the equator to the poles and from the surface down to the bottom at a depth of six English miles.

The visible rays of the sun penetrate the ocean waters down to a depth of over 3000 feet, but even the actinic rays do not penetrate beyond 5000 feet. This superficial layer affected by sunlight is called the photic zone of the ocean, and throughout its whole extent vegetable life is present, often in great abundance, in the form of vast floating meadows of unicellular algæ. Herbivorous animals feed on these minute algæ and other plants, and

the herbivores are in turn the prey of carnivorous animals, just as on the land-surfaces. Beneath the photic zone living plants are not present. However, the dead remains of the algæ which inhabit the photic zone in falling to the bottom supply food for animals in the intermediate waters, for those fixed organisms which catch the small organic particles as they settle on the bottom, and for the echinoderms and other invertebrates which crawl along the bottom and eat the oozes, muds, and clays. These in turn are preyed on by the carnivores which are also present. All marine animals derive their food primarily from marine algæ, to which must be added the nutritive material carried into the ocean by rivers.

Remembering the great depth of the ocean, that plants may function at a depth of 3000 or 4000 feet, and that animals exist throughout the whole ocean, we may conclude that the total quantity of living matter in the ocean greatly exceeds that on the land-surfaces of the globe.

As has been pointed out in previous chapters, the physical conditions in the ocean to which organisms have adapted themselves are most varied. Some marine organisms in the Arctic and Antarctic regions live the whole year round in water having a temperature below

the freezing point of fresh water, while very closely related species in the tropics pass their lives in water with a temperature of 80° F. The metabolism—the rate of growth, of digestion, and of reproduction—is greatly retarded

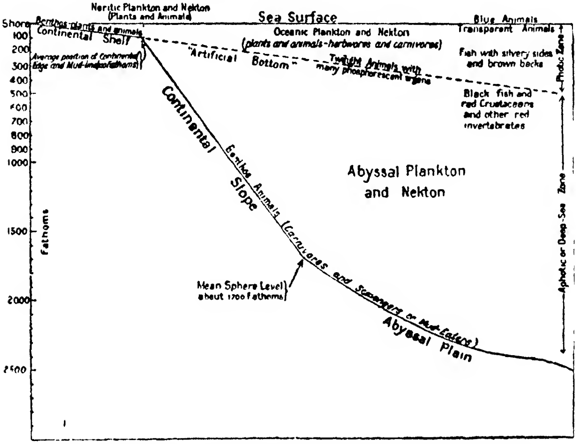

FIG. 8.—Diagram showing the oceanic faunal and floral areas.

in the cold polar waters and accelerated in the warm equatorial waters. In the shallow waters marine organisms must accommodate themselves to strong currents, to abundant sunlight, to rapid changes of temperature and salinity, and hold their own against many varied competitors and enemies, whereas in the deep sea there is no sunlight, a nearly constant low temperature, and no rapid cur-

rents, the general conditions being very uniform throughout the year. In the intermediate depths between the surface and the bottom there are curious adaptations to twilight, to changing viscosity, depth, pressure, and to variations in other physical and biological conditions.

The oceanic faunal and floral areas are indicated diagrammatically in Fig. 8, and may be briefly described as follows :—

I. *The Photic Zone* is the superficial region of the ocean illumined by sunlight, extending deeper in the open ocean and in equatorial regions than near land and in high latitudes. It is subdivided into the *neritic* and *oceanic* areas. The *neritic* area surrounds all continents and islands from surface to bottom within the limits of the 100 fathoms line of depth. The waters of this area are much agitated by winds, waves and currents, and present great variations in composition, salinity, temperature and viscosity; they contain plants and animals and a large proportion of pelagic larvæ of benthonic animals living on the continental shelf. The nature of the bottom on this neritic area likewise varies greatly, and may be composed of rocks, boulders, sands, marls and muds. The *oceanic* area of the photic zone, being removed from the immediate influence of the dry land

and of the floor of the ocean, presents great uniformity of physical conditions when compared with those prevailing in the neritic area. Temperature, salinity and viscosity vary with latitude, but the pelagic types of organisms are more widely distributed in the open ocean than in the neritic area.

Throughout the whole photic zone chlorophyllous plants (mostly algæ) are abundant and universal, while the animals of the zone are both herbivorous and carnivorous.

II.—The *Aphotic* or *Deep-Sea Zone* extends from the lower limit of the photic zone down to the bottom of the greatest " deeps." Daylight does not penetrate to the waters of this zone, the sun's rays being almost wholly absorbed in passing through the upper layers, but phosphorescent light, produced by organisms, appears to play a great rôle throughout the whole zone. The temperature is low except in some enclosed seas. There is little variation in the salinity and viscosity. The pressure varies with the depth, but physiological functions are little disturbed even by excessive pressure, when once equilibrium is established within and without the organism. Living chlorophyllous plants (algæ) are absent, and the animals are carnivorous and scavengers or mud-eaters. The bottom conditions on the floor of this deep-sea zone are

very uniform, with deposits of soft muds, organic oozes, and red clays. Rocks and stones are only occasionally present.

The limit between the photic and aphotic zones is deeper at the equator than towards the poles, and is the most interesting region of the ocean because of the change in the physical conditions which there takes place. Sunlight has there its limit of penetration, and in the tropics there is a great change in the temperature. On the bottom currents and waves have little effect, and the organisms exhibit adaptation to these changed conditions in their colours, eyes, phosphorescent organs and tentacular appendages. The mud-line is evidently a great feeding ground, for at this depth the minute organic particles settle on the bottom, and in mid-ocean similar particles are much retarded in their fall by the great increase in the viscosity of the water, thus producing a sort of "artificial bottom" which seems likewise to be a great feeding ground.

In treating of the forms of life in ocean waters it will be convenient to speak in this chapter of the plants and in the following chapter of the animals.

Plants in the Ocean.—Phanerogamic plants are represented in the ocean by the family Zosteraceæ. *Zostera marina* (eel-grass) is very

common along the coasts of the Atlantic in sheltered localities with a soft muddy bottom, and in such positions this plant provides shelter for some distinct and characteristic species of animals, which live mainly, perhaps exclusively, in its vicinity.

The vast majority of sea-plants belong, however, to the algæ. Owing to the vertical direction of the sun's rays and their consequent greater penetration in the tropics, algæ are found at a greater depth towards the equatorial regions than towards the poles. They differ from terrestrial plants in finding their nourishment dissolved in sea-water, and this being uniformly distributed around them they can take in food throughout the entire surface of the organism. They all possess green chlorophyll—that magician which, conjuring with the sunbeams, is able to build up organic compounds from inorganic constituents. The green chlorophyll is often masked by other pigments of a red, brown, blue, or yellow colour.

The algæ may be divided according to habit into two main groups: (1) those attached to the bottom (Benthos), and (2) those which pass their whole life-cycle floating in the water (Phytoplankton), and in accordance with their predominant colouring they have been arranged in four groups:—

(1) Chlorophyceæ, or green algæ;
(2) Cyanophyceæ, or blue-green algæ;
(3) Phæophyceæ, or brown algæ;
(4) Rhodophyceæ, or red algæ.

The green and blue-green species live in shallower water than the brown and red species, but blue algæ living in deep water may become red, and red algæ may become purple, green, or yellow, according to the amount of, and exposure to, sunlight.

Attached Algæ.—The attached algæ include both brown and red, and are found along practically all coasts, except in polar seas, where the rocks are scoured bare of all life by the grinding action of ice. The brown algæ are the commonest and the most characteristic of marine plants, and are sometimes of great size, *Macrocystis pyrifera* of the Southern Ocean occasionally reaching a length of 700 or 800 feet. The common brown algæ of the littoral zone belong to the genus *Fucus*, and immediately below this area at low-water mark the genus *Laminaria* prevails. Associated with these plants there is in each case a special and different assemblage of animals.

The famous Gulf Weed characteristic of the Sargasso Sea in the North Atlantic belongs to the brown algæ. It is named *Sargassum bacciferum*, and is easily recognised by its small berry-like bladders. This floating weed

is always destitute of organs of reproduction, and it is believed that it grows vegetatively, although this has been disputed. It is supposed that the older patches gradually lose their power of floating, and perish by sinking in deep water. Attached forms of *Sargassum* with reproductive organs have been found at Bermuda, at the West Indies, and on the coast of Central America. The floating masses of Gulf Weed are believed to be continually replenished by additional supplies torn from the coasts by waves and carried by currents until they accumulate in the great Atlantic whirl which surrounds the Sargasso Sea. They become covered with white patches of polyzoa and serpulæ, and quite a large number of other animals (small fishes, crabs, prawns, molluscs, etc.) live on these masses of weed in the Sargasso Sea, all exhibiting remarkable adaptive colouring, although none of them belong properly to the open ocean.

The red algæ present two very different types. The one is soft and delicate, with extremely fine ramifications, like the *Polysiphonia* of the English coasts. The other grows in round masses, or with ramifications, always encrusted with calcareous matter. These are the corallines (Nullipores), which play a great rôle in tropical water, some forms, like *Lithothamnium*, making up a large part

of coral reefs, other species encrusting rocks and protecting them from erosion. They date back at least to the Jurassic period, and in Tertiary times they built up a large part of certain geological formations.

Floating Algæ.—Turning now to the pelagic algæ making up the phytoplankton, we find that these, unlike the attached algæ along the coasts, are all small, the majority being of microscopic dimensions. They are found floating everywhere within the photic zone in countless myriads, being, however, most abundant in the subsurface layers of this zone, and are of the greatest importance in the economy of the sea, for, with the exception of the fixed algæ and matters carried down from the land by rivers, they build up all the organic substances upon which marine animals depend for food. The same rule holds in the sea as on the land, that all animal life depends directly or indirectly on vegetable life.

The marine phytoplankton includes green, blue-green, and brown algæ. The vast majority belong to the brown algæ, the blue-green algæ being represented only by the Oscillatoriaceæ, and the green algæ only by *Halosphæra.*

Brown Algæ (Phæophyceæ) include diatoms, peridineans, coccolithophoridæ, and xanthellæ.

(1) *Diatoms.*—These organisms are found throughout the world in all fresh and salt water and in damp places. They occur not only floating in the ocean but attached to other algæ and to animals in almost all regions. They are distinguished from other algæ in possessing thin silicated cell-walls (often beautifully sculptured), which consist of two similar valves, or frustules, fitting into one another like the top and bottom of a pill-box. New cells are produced by division. Some species are capable of motion, and glide over the sand or mud or through the water; in other species the separate frustules glide over each other with a back and forward motion.

The pelagic species (see Plate VII.), to which reference is here specially limited, have generally thinner walls than fixed shore or neritic species, and have frequently highly developed suspension-organs. They have been divided into four groups:—

(*a*) The bladder type, of which *Coscinodiscus rex* (over a millimetre in diameter) is the largest.

(*b*) The ribbon type, with flattened cells, several cells being united together into ribbon-like colonies, as in *Fragillaria oceanica.*

(*c*) The hair type with cells very much prolonged in one direction or united into elongated colonies. The elongated form tends

to keep them in a horizontal position in the water, and so prevent them from sinking. *Rhizosolenia* offers an example of this type.

(*d*) The branching type with the surface of the cell enlarged by various kinds of hair-shaped outgrowths. *Chætoceras*, usually associated in chains, is a well-known example of this type.

Many of these require to vary their form in order to adapt their floating power to the varying conditions of viscosity in ocean water. Their tendency to sink increases as the viscosity decreases with a rise of temperature, and they then develop special suspension-organs to keep them near the surface. In temperate regions some species may have distinct summer and winter forms so unlike that they have been regarded as different species. In the tropics there are species corresponding to the summer forms, and in polar waters species corresponding to the winter forms. The summer forms have usually thinner cell-walls and a more slender structure.

In coastal waters, where the physical conditions vary far more than in the open sea, most diatoms have a special adaptation (unknown in true oceanic species), called resting spores, to enable them to pass through unfavourable seasons of the year. The cell-

contents shrink into a dense mass in the middle of the cell, and then develop a new and thick wall within the old cell-wall, which is discarded as soon as the resting spore is fully enveloped. These spores, having a greater specific weight, sink either into deep water or to the bottom in coastal areas, where they lie for months until conditions are again favourable for a new start. The germination of these resting spores has not yet been described.

In the open ocean diatoms occur in greatest abundance where there is an admixture of muddy water from the land and where the salinity is relatively low, for instance off the embouchures of rivers, in the Indo-Pacific region, where the largest rainfall in the world occurs, and towards the Arctic and Antarctic ice. Their abundance appears to be related to the presence of colloidal silica or the hydrated silicate of alumina in these areas rather than to temperature, for they are found abundantly in the tropics as well as towards the poles. In the northern and tropical Pacific, where the salinity of the surface water is relatively low, all silica-secreting organisms are more abundant than in the salter waters of the Atlantic. It is well known that the addition of some salt to muddy water at once clears it by precipitating the clayey matter. There is evidently a lack of silica in solution

or suspension in the ocean-waters with high salinity, so that this distribution of silica-secreting organisms is correlated with the law of the minimum in agriculture. In the great Southern Ocean, and in some other areas of limited extent, the dead frustules of diatoms accumulate on the bottom in such numbers that the deposit is called diatom ooze.

(2) *Peridineans.*—These are mobile unicellular algæ, or organisms which function as algæ, having a cell-wall of an organic substance like cellulose, which dissolves after the death of the organism. Consequently the remains of these organisms are never detected in marine deposits. They occur in enormous quantities, and in many varieties, while most of them are brilliantly phosphorescent. *Peridinium depressum* is a typical species. A distinct difference is seen between the anterior and posterior ends, and also between the dorsal and ventral surfaces. There are characteristic furrows on both front and back, and a third furrow, known as the ring-furrow, encircles the cell. One cilium projects through a pore in the posterior furrow, and can be withdrawn spirally into a sheath; another cilium lies in the ring-furrow. Gran states that in *Peridinium* reproduction does not take place by cell-division, but the cell-contents are changed into one, two or four

naked spores that are shed from the original cell, and gradually develop new cell-walls of their own. In *Ceratium* the reproduction is by division, as in the diatoms. The cells very often hang together in chains, and it can be seen that the horns of the cell vary considerably in form from one generation to another. *Ceratium tripos* may give rise to an intermediate generation of quite a different type—much smaller, with short straight horns. In the same species gemmation may take place instead of normal cell division. The full meaning of these variations has not yet been made out.

Pyrocystis, discovered during the "Challenger" Expedition, belongs to the Peridineæ, and is very abundant in all tropical and subtropical waters where the temperature exceeds 68° F. and where the salinity is not lowered by the presence of coast waters. *Pyrocystis noctiluca* is spherical in form and 0·6 to 0·8 mm. in diameter, with brown pigment granules. It is about the same size as the animal-flagellate *Noctiluca*, which never has brown granules, and flourishes in coast waters, while *Pyrocystis* occupies the open water far from land chiefly in intertropical regions. Both *Pyrocystis* and *Noctiluca* are brilliantly phosphorescent.

(3) *Coccolithophoridæ* are brown globular flagellates, which secrete calcareous button-

like shields, sometimes with a central spine, and are generally limited to the warmer areas of the ocean. These calcareous shields are called coccoliths and rhabdoliths, and were known from deep-sea deposits long before the living organisms, coccospheres and rhabdospheres, were discovered by the "Challenger" in the surface waters. They have been met with in geological deposits as ancient as the Cambrian Period, showing that they have retained their shape practically unaltered through long ages. These rhabdospheres and coccospheres may pass through the finest tow-nets, and for a long time some naturalists did not believe in their existence. They were first detected during the "Challenger" Expedition, entangled in the protoplasmic threads of pelagic foraminifera and radiolaria and in the stomachs of salpæ and pteropods, and are now collected plentifully by means of the centrifuge from water-samples obtained at different depths by the water-bottle.

In the Arctic and Antarctic seas the coccospheres are replaced by species without calcareous shields, such as *Tetraspora* (*Phæocystis*) *poucheti* which occurs in enormous floating banks.

(4) *Xanthellæ.*—Besides the coccolithophoridæ there are other minute brown algæ in the surface waters of the tropical regions

which are as yet imperfectly known, though they probably play a great rôle in the economy of the ocean. Such are the xanthellæ or "yellow cells" of the radiolarians—a case of symbiosis. This association of plant and animal cells is evidently beneficial to both, for the starch developed by the yellow cells with the formation of oxygen may serve as nutriment to the animal, while the carbonic acid yielded by the animal is available to the plant-cell. These yellow cells occur also in foraminifera (*Globigerina* and *Orbitolites*), and in corals and other invertebrates, as well as floating independently in the ocean.

In the legion of the Radiolaria called Phæodaria, which inhabit the deep sea, the place of the yellow cells in the other Radiolaria is apparently taken by the phæodellæ, dark-coloured cells, which may possibly be a lower form of algal life than the yellow cells and capable of evolving oxygen under the influence of the phosphorescence of deep-sea animals.

Blue-Green Algæ (Cyanophyceæ) predominate over all other algæ in fresh water, but in the sea they are represented by only a few species and genera. The well-known "blossoming" or "water-bloom" of lakes at certain times of the year is due to the enormous development of certain species of Oscilla-

toriaceæ, and something similar occurs in the ocean. The best-known oceanic genus is *Trichodesmium*, consisting of brownish, yellow, or red cells collected together into little bundles, which have in the water the appearance of chopped hay. In calm weather these clusters rise to the surface by means of air vacuoles, and at times form a yellowish-brown scum of great extent, which is called by sailors "whales' spawn." When this scum occurs in great quantity a disagreeable pungent smell is given off, and sometimes it has an ill effect on the eyes and nose. Other species of Oscillatoriaceæ are known to have noxious properties. These blue-green algæ, in addition to chlorophyll, contain phycocyanin and other colouring matters, which modify the absorption spectra, and thus affect the assimilation of carbon from carbonic acid in the presence of sunlight and the liberation of oxygen. This phycocyanin is probably set free in the processes of putrefaction, and may be the cause of the disagreeable effects noted above.

A very minute blue-green alga (*Richelia intracellularis*) occurs within the cells of *Rhizosolenia*, and apparently reproduces itself inside the diatom cell. It is not yet known how it penetrates into the diatom, but it has been suggested that it probably does so during an early stage in the life-history of

Rhizosolenia, before it has developed its silicated cell-wall.

Green Algæ (Chlorophyceæ) are poorly represented in the ocean, and in the phytoplankton practically only by the genus *Halosphæra,* a small spherical alga of bright green colour, known to Italian fishermen as "*punti verdi*" (green spots). Indeed the green colour so characteristic of most terrestrial plants is found in only a few marine plants. *Halosphæra* occurs nearly everywhere in the surface and subsurface waters, except in the Arctic and Antarctic, but never in great abundance. Unlike most algæ, it is reproduced by zoospores. It has been taken in closing nets near the lowest limit of the penetration of sunlight in the open ocean, but in this position was probably dead and falling to the bottom.

Bacteria.—These plants are often regarded as the lowest forms of life. This does not mean that they were the first living organisms on the earth, where life probably appeared long before bacteria. They have doubtless undergone evolution, and had not always their present appearance. They are related to the Fungi, and are the most numerous and most widely distributed of living things, being present everywhere in earth, air and water, and occurring as parasites in plants and animals. Under the microscope they appear

as round dots, rods, or threads; they are colourless and contain no chlorophyll, and have an envelope or capsule of cellulose or allied substance. They multiply by division or by spores. Life as a whole could not continue without bacteria; they do not originate life, but supply life with the necessary material. Plants without chlorophyll and animals dissipate the energy accumulated by chlorophyllous plants, which derived this energy wholly from the rays of the sun.

Bacteria and decomposing organic matter are always associated, so that the presence of bacteria throughout the whole mass of the ocean—even in the greatest depths and in the coldest water—was inferred long before their presence was detected by actual observations.

The vast majority of bacteria cannot live unless they have organic substances both carbonaceous and nitrogenous at their disposal. They include those which produce fermentation (decomposition of non-nitrogenous substances) and those which produce putrefaction (decomposition of nitrogenous substances). The excretions and dead bodies of animals, the fragments of tissues and cells, the waste of domestic and industrial life, all eventually find their way into the soil and into the ocean. Generally these substances are not in a fit chemical state to be utilised

at once by plants as food ; it is necessary that they should first go through a transformation in which their chemical composition becomes changed. It is as the agents of this change or transformation that bacteria play their greatest rôle in the world of life. In short, the final destiny of all living substance is, sooner or later, directly or indirectly, to become food for bacteria.

Through the activity of an enzyme produced by certain bacteria a simple excretory product may be converted into carbonate of ammonia. Now, while green plants or algæ can derive some nitrogen from ammoniacal compounds, it is a well-established fact that nitrogen may be obtained by plants much more readily from nitrates. There are then still other bacteria—nitrifying bacteria—which oxidise the ammoniacal nitrogen into the more available form of nitrites and nitrates; one group attacks the ammonium compounds, changing them to nitrites, another group completes the oxidation into nitrates. Denitrifying bacteria reverse this action, and reduce nitrates to nitrites, nitrites to ammonia, and ammonia to free nitrogen.

There is thus a never-ending cycle : through the agency of chlorophyll in sunlight there is a progressive complexity in the living organic matter which is built up, vegetable proteins

being formed; animals may devour these vegetable products, and raise the living substances to a still higher level of complexity, animal proteins being formed. However, on the death of all animals and plants these complex organic substances are broken down, through the agency of bacteria, to carbon dioxide and nitrogen or its simplest compounds, which have relatively little stored potential energy.

The nitrifying bacteria appear to require no organic compounds for their nutrition, and the bacteria of root-nodules, given the most minute quantity of organic carbon, can derive all their nitrogen from the atmosphere. With these may be classed those forms which are able, with a very small supply of organic matter, to break up specific inorganic bodies and derive energy from the process (sulphur and iron bacteria). The chemical changes are not well understood, but they indicate that these organisms, without chlorophyll and sunlight, can appropriate the carbon dioxide from the atmosphere, as well as assimilate and store up free nitrogen. These bacteria thus give some indication of how the first forms of life to appear on the earth obtained their nourishment, and they may possibly form an exception to the general statement that green chlorophyll-bearing

plants are alone able with the aid of sunlight to assimilate the carbon dioxide of the atmosphere and to build up carbohydrates.

It follows from what has been stated above that in the ocean bacteria are most abundant near shore and in shallow water, where there is a large supply of dead organic matter, and become less and less abundant far out at sea and in deep and cold water. They seem to be especially abundant at what has been called the "mud-line," that is at the position where all minute organic and inorganic particles settle on the bottom, and form mud—the humus of the ocean—in place of sand or gravel. In the surface waters again they are extremely abundant and active where cold and warm currents meet. Here, owing to the rise of temperature, the bacteria which had been dormant or lethargic in the cold water become active and break down into nitrites and nitrates the albuminoid ammonia which had been protected by the low temperature from decomposition in polar currents or cold upwelling waters from the deep sea; thus abundant food for plants is formed. It has frequently been remarked that the pelagic algæ are especially numerous in such areas, for instance throughout the whole Southern Ocean and to the south-west of Iceland in the North Atlantic.

While bacteria are usually killed by a temperature of 140° F., they become merely quiescent by repeated freezings, and survive very low temperatures. If the temperature sinks below a certain point organic substances cannot putrefy; when the frozen Siberian mammoths were discovered, their flesh was so little changed that it was eaten by the hunters' dogs. If bacteria did not exist in the cold water of the deep sea it would be difficult to understand how the soft parts of whales and fishes have undergone decomposition.

Phosphorescent bacteria are abundant in the ocean, indeed they seem to be limited to ocean water, for they have never been observed in fresh water. These bacteria are present on dead fishes and other marine organisms at all temperatures, but especially at relatively high temperatures.

CHAPTER VIII

LIFE IN THE OCEAN: ANIMALS

MARINE animals may be divided into those that are warm-blooded and those that are cold-blooded, or better still into animals whose blood is usually at a more or less constant temperature whatever the external temperature may be, and animals whose blood-temperature is always the same as, or very little above, the temperature of the water in which they are living. To the warm-blooded animals belong all the marine air-breathing mammals, such as whales, porpoises, dolphins, seals, walruses, etc., the modern whales being the largest creatures that have ever lived on our earth. All these mammals have descended from terrestrial species which have adapted themselves to an aquatic mode of life. In these marine mammals the blood-temperature ranges from 98° to 104° F., and does not sensibly vary whether they be found in the ice-cold waters of the polar regions or the warm waters of equatorial seas. If some

birds—like the penguins—are to be regarded as marine creatures, then they have a still higher blood-temperature, which remains practically constant although the external conditions vary greatly.

The vast majority of marine animals belong to the second group, in which the blood-temperature is the same as that of the surrounding water or a very little higher. This group includes the fishes and all invertebrates. In the tunny-fish the temperature of the blood was observed to be sometimes as much as 6° F. above that of the surrounding water, but this was after great exertion and is exceptional. There are in the polar regions many species, belonging to nearly all the marine groups, which pass the whole of their lives in water having a temperature below the freezing point of fresh water. In the tropics, however, animals belonging to the same groups, star-fishes for example, pass the whole of their existence in water having a temperature of about 80° F. It is well known that chemical reactions are so influenced by temperature that the velocity of a reaction is doubled or trebled when the temperature is increased by 18° F. This is known as van t'Hoff's law, and is strictly applicable to biochemical reactions in plants. The evidence available shows that the same may be inferred with regard to

the metabolism in animals, and this fact may explain many puzzling problems in marine biology.

We shall in the first instance refer to animals which inhabit the surface, sub-surface and intermediate waters of the ocean (Plankton), and then to those which are attached to or crawl over the ocean-floor (Benthos).

Plankton Fauna.—The great variety of plant-life in the surface and sub-surface waters of the ocean, and the variations brought about by changes in temperature, viscosity and other physical conditions, have been referred to at the beginning of the preceding chapter. Animal life is equally abundant, and in even greater variety, in the surface and sub-surface waters, and is grouped into (1) plankton, both neritic and oceanic—animals carried along by the currents—and (2) nekton—animals which can swim against currents.

Almost all classes of marine animals are represented in the plankton fauna in either the colder or the warmer areas: reptiles, fishes, tunicates, crustaceans, molluscs, worms, cœlenterates and protozoa. The sponges are unrepresented. The great class of echinoderms seems to be represented only by the pelagic holothurian *Pelagothuria,* although the larval stages are numerous, especially where the sea is shallow, and the large class

of insects is represented by only a few species of *Halobates*.

The protozoa (foraminifera and radiolaria) form a most important item in the plankton, for though of microscopic dimensions they swarm in countless myriads in tropical and temperate regions (see Plate VII. for radiolaria, and Plate IX. for foraminifera), and deposits largely composed of their dead shells and skeletons cover extensive areas of the sea-floor in different parts of the world.

The crustacea are probably the most abundant of all pelagic animals, and especially the smaller forms, like the copepoda and amphipoda, the small size of which is counterbalanced by the enormous number of individuals.

The pelagic molluscs (pteropods and heteropods) are specially characteristic of the warmer regions of the ocean (see Plate VIII.), where their shells fall to the bottom in such numbers as to form in moderate depths a large part of the deposit called pteropod ooze.

The pelagic tunicates (*Salpa*, *Doliolum*, *Pyrosoma*, *Appendicularia*) are important members of the plankton, and many species of fishes and cephalopods, being powerful swimmers, are included among the nekton.

Pelagic larvæ of benthonic animals are abundant near shore in shallow water, but

become less numerous farther out to sea. In tropical and sub-tropical regions there are many overgrown larval forms (*Plagusia*, *Phyllosoma*, *Alima*, *Erichthus*, etc.), which are supposed to have been carried by currents from the shallow waters near shore into the open ocean, where they could not find congenial conditions for their development sexually, and hence have grown to a great size. It is still maintained by some authors that the *Leptocephalus* of the common eel is a larva of this kind. If it be quite normal, it has the peculiarity of being reduced in size on passing from the leptocephalid to the elver stage. The salmon runs into rivers and lakes to spawn, but the fresh-water eel puts on a silvery coat and descends to the ocean to spawn, though as yet its eggs have not been found. The youngest larval stages known were taken in the Sargasso Sea by the "Michael Sars" in 1910.

The assemblage of pelagic or planktonic organisms within the photic zone of the ocean is self-sufficient and self-supporting. The minute plants, like peridineans and diatoms, build up organic substances by the aid of chlorophyll and sunlight, and furnish food for such creatures as copepods and amphipods, which in turn are food for fishes, birds and whales. Here we

have an example of one of the many existing nutritive chains in the ocean : all the organic matter elaborated in the bodies of these organisms is, after death, attacked by bacteria, and broken down to ammonia, nitrites, and nitrates to form the food of the pelagic algæ, thus carrying on this cycle of anabolism and katabolism.

Influence of Temperature.—In Arctic and Antarctic regions, when tow-nets are drawn through the ocean waters, vast numbers of crustaceans—schizopods, copepods and amphipods—are captured which belong to relatively few genera and species. When tow-nets are drawn through tropical waters, they usually capture similar pelagic creatures, but while the quantity of organic matter in them is much less than in the polar seas, the numbers of genera and species greatly exceed those found in the cold waters toward the north and south. This contrast is apparently to be accounted for by the rate of metabolism in the organisms, to which reference has just been made. It seems evident that the organisms captured in the cold polar waters are of very different ages, eggs and young and adults being found at all seasons in the same hauls ; some of these adults may be ten, twenty, or more years of age. The actions of enzymes, of bacteria, and of putrefaction are all slowed down in the

low temperature conditions. In tropical waters, on the other hand, all these processes are accelerated, and the various phases in the life-history of these organisms are passed through rapidly; it is unlikely that any of these minute organisms in tropical seas are older than some days, weeks or months. It is in this way that we may account for the greater quantity of organic matter in cold polar waters, which furnishes abundant food for such huge animals as the whalebone whales. The stomachs of these whales when killed are sometimes found to be so crammed with copepods and other crustaceans that they may be dug out with a spade. In the equatorial waters the toothed whales feed, not on these small plankton organisms, but on cuttle-fish, fishes, and other large creatures. It is also probable that this temperature relation is correlated with the fact that in the cold polar waters the individuals are many, while the genera and species are few, and that in tropical waters the individuals are relatively few while the genera and species are many.

Another peculiarity depending apparently on temperature is the fact that the development of a large number of polar marine animals is direct. During the "Knight Errant" Expedition in the Faroe Channel many hundreds of holothurians (*Lætmogone violacea*)

were taken in a haul of the trawl in 555 fathoms, and at another station many hundreds of pycnogonids (*Nymphon robustum*) were taken in a trawling from 540 fathoms. This exuberant development of individuals belonging to a single species at one spot in the colder regions of the ocean is believed to be dependent upon direct development, so that the young spread over the sea-bed without the intervention of a pelagic stage.

In the tow-net catches in the Arctic and Antarctic there are relatively very few pelagic larvæ of benthonic species. In the Antarctic the "Challenger" recorded only one echinoderm larva in the surface waters. This was subsequently taken by the British National Antarctic Expedition and by the German South Polar Expedition. It has been described under the name of *Auricularia antarctica*, and is regarded by Mortensen as the larva of a holothurian. On the other hand, many echinoderms (asterids, ophiurids, echinids and holothurians) were dredged with eggs and with young in various stages of development clinging to the parents. In temperate regions pelagic larvæ are abundant during the warmer months of the year, but almost absent in the winter, while in the equatorial regions they are always present in the tow-nets, especially in coastal waters.

Again, the secretion of carbonate of lime by organisms is very much retarded in cold water as compared with warm water. In cold water it is believed that calcite is laid down, while in warm water aragonite is deposited. As an illustration it may be mentioned that in the tropical waters there are about 35 species of shelled pteropods and 32 species of heteropods. These gradually disappear as we proceed from the equator towards either pole, till in truly polar waters only one small shelled species of *Limacina* is to be found in the Arctic and another allied species in the Antarctic. Meisenheimer states that the pteropod *Limacina helicina* occurs both in the Arctic and Antarctic, while *Limacina retroversa* occurs in the northern and southern temperate regions, though absent from the warmer tropical belt. Some authors, on the other hand, do not regard these northern and southern forms as identical, but rather as distinct varieties.

Quite similar is the distribution of the pelagic foraminifera. Towards the equator more than twenty species may be found in the tow-nets, but they gradually disappear as we proceed into colder water towards the poles; only one species of *Globigerina* (*G. pachyderma*) is found living in the Arctic surface waters and another species (*G. dutertrei*) in the Ant-

arctic waters. Some authors regard these two species as identical.

The gigantic coral reefs and islands of the ocean, as well as the dead shells making up the globigerina and pteropod oozes of the ocean-floor, present excellent evidence of the metabolic activity of animals and plants in the warmest waters of the globe. The living mantle of organic matter over the surface of the coral reefs may not at any moment be very large in amount, but the presence of the reefs, and the rate at which the calcium carbonate skeletons are laid down, clearly indicate a much greater metabolic activity than is to be found anywhere in the Arctic or Antarctic seas. In the cold water of the deep sea there are among benthonic organisms, on the other hand, no large molluscan or other calcareous shells. The largest mollusc shell dredged by the "Challenger" in deep water was about six and a half inches in length and was thin and transparent.

Viscosity.—Still another condition depending on temperature is the viscosity of the sea-water (see Chapter V.), which plays an important rôle in the development of suspension-organs in plankton animals as well as plants. In the surface waters of the tropics a temperature of 80°F. is found, and the viscosity is, as we have seen, only one-half of

that met with at the lower limit of the photic zone, where the temperature is 40° F. It follows that organisms sink twice as fast in the warmer water above as in the colder water below, and it is necessary for them to develop various kinds of floating apparatus, so as to increase or diminish their surface resistance. These floating devices include secretion of fats and oils, development of air-bladders, reduction of size, variation in shape, and production of various forms of appendages. As in the case of cold-water marine plants, polar marine animals do not require to develop suspension-organs, because of the small variation in the viscosity of the water in surface and deep layers.

Relation of the Pelagic Fauna to Penetration of Light.—The animals captured near the lower limit of light-penetration, that is in tropical regions in depths of about 500 fathoms, have been called bathypelagic or twilight animals. There is at this depth a rather sudden change of temperature, salinity and viscosity, and in consequence we find many adaptations to these peculiar physical conditions, for instance as regards colour and amount of pigmentation, and the development of floating contrivances, and of eyes and light-organs.

Floating at the surface of the ocean we have

a series of blue-coloured animals, like *Porpita, Velella, Physalia* and *Ianthina*, which viewed from below must be nearly invisible, hence protected from enemies.

Immediately below the surface most animals are transparent and colourless, like the leptocephalids and many other larvæ, which when taken from the tow-nets are often distinguishable only by their little black eyes, their blood being devoid of hæmoglobin and the entire body perfectly transparent. Others are silvery, with a bluish back, like the herrings and flying fishes. Animals living in the vicinity of floating objects, such as logs of wood or clusters of gulf weed, exhibit a marvellous resemblance in colouring to the objects they accompany : as typical examples of such protective colouring we may cite the little crab (*Planes minutus*) and the little fish (*Antennarius marmoratus*) associated with the floating gulf-weed of the Sargasso Sea.

In depths of 100 or 200 fathoms the fishes are usually laterally compressed, grey in colour or with silvery sheen, often iridescent, on the sides, and blue-black or brown on the back. This arrangement seems admirably adapted for rendering the animals invisible when viewed either from above or from below—the fish *Argyropelecus* is a good example.

In depths beyond 300 fathoms the animals are characterised by reddish and dark colours: thus the medusæ show dark brown and red colours, the pteropods dark violet, the fishes black or dark violet, the worms and crustaceans red.

These variations of colour seem to be correlated with the amount of sunlight penetrating to the various depths, for the dark-coloured bathypelagic forms are found in deeper water in the tropics than in temperate regions where the penetration of light is less. It has been shown by the "Michael Sars" Expedition that the dark-coloured fishes undertake vertical migrations during the night, and have consequently a very considerable adaptation to changes of temperature and pressure. The amount of pigmentation in certain forms like medusæ and crustaceans seems also to be regulated by the amount of light, increasing in intensity with increase of depth.

Phosphorescent Light.—We have already referred to the extraordinary fact that no phosphorescent organisms have been found in fresh water, even phosphorescent bacteria requiring sodium chloride in the medium in which they are cultivated. The power of emitting phosphorescent light is widely distributed in nearly all groups of marine organisms, including bacteria, peridineans, flagel-

lates, cœlenterates, crustaceans, cephalopods, tunicates and fishes. The fact that some creatures have this power and others have not, and the distribution of phosphorescent organisms as regards depth, are among those puzzling phenomena with which the marine biologist has to deal. The development of phosphorescent organs appears to be greatest in warm water, but it is also found in cold waters, as in the case of *Peridinium* and *Nyctiphanes*.

Sometimes the light is due to the secretion of a slimy luminous substance, which may cover the entire body ; sometimes it proceeds from a nucleus ; sometimes it is produced by special light-organs more or less complicated in structure, from a simple luminous cell in the epithelium to complex glandular bodies having a lens and reflector, functioning somewhat after the manner of a " bull's eye lantern."

Development of Light-Organs.—Light-organs occur mainly in pelagic animals and, as regards the fishes, are characteristic of those forms living in depths down to 300 fathoms. The size of the light-organs seems to correspond with different depths, the larger organs being found in fishes living in the sub-surface waters. Thus of the six species of *Cyclothone* five live in deep water, and these are black and have

small light-organs, while one species (*C. signata*) lives in much shallower water, is grey in colour, and has large light-organs. The surface forms of the scopelid genus *Myctophum* have large light-organs, while the deep-water forms of the same genus have very small light-organs. During the "Michael Sars" Expedition in the North Atlantic the fishes taken in depths beyond 400 fathoms had usually either no light-organs or very small ones, while those taken between 100 and 300 fathoms had large light-organs.

Development of Eyes.—Evidently the size of the eye is correlated with phosphorescent light and the penetration of sunlight, for among pelagic fishes a great change in the size of the eye is noticeable in those living near the lower limit of the photic zone as compared with those living in the lesser depths. Thus in many of the fishes taken from depths of 100 to 300 fathoms the diameter of the eye is about one-half to one-quarter of the length of the head, while in those taken beyond 300 fathoms the eye may be only one-twelfth or one-fifteenth of the head, or it may be absent altogether. It is interesting to note that the only blind squid known was taken at a depth of 800 fathoms. Among the crustacea a decrease in the size of the eye with increase of depth has also been noticed: in many

amphipods living in the surface waters the entire head is occupied by the two large eyes; in certain decapods living in depths less than 100 fathoms the diameter of the eye is about one-sixth the length of the carapace, while in those from about 300 fathoms the relation is about one-tenth, and in those from 500 or 600 fathoms it may be as low as one-twentieth.

Peculiar stalked eyes have been observed in a few pelagic larval fishes, but they probably develop into normal eyes during the later stages. A stalk-eyed cuttlefish has also been taken at a depth of 100 fathoms. Telescopic eyes are known in fishes from depths less than 300 fathoms, usually such as float rather than swim, and as they point upwards they seem well adapted to receive the faint vertical rays of light.

It must be pointed out that sometimes the eyes of benthonic animals become larger with increase of depth, and it is possible that this is for the purpose of being sensitive to phosphorescent light.

Intermediate Water Fauna.—Up to the present time it is impossible to make any quite satisfactory statements as to the distribution of animals living in the great intermediate region between the lower limit of the photic zone and the bottom. While many animals, like some of the Challengeridæ among the

radiolaria and members of some of the higher groups, apparently live exclusively in this area, the limits of their bathymetrical distribution have not been ascertained. So far as they have proceeded the investigations seem to show that the organisms inhabiting this intermediate zone of water are not so numerous as those in the layers nearer the surface and nearer the bottom.

Benthos.—Passing from pelagic to benthonic animals, it seems to be the general rule that the greatest profusion of bottom-living animals is to be found in coastal waters, and that they gradually decrease in abundance on proceeding farther and farther from land into deeper and deeper water, until a minimum (but not a zero) is reached in the red clay areas of the abyssal plain. Distance from a continental shore seems to be as a rule a more important factor in the distribution of the benthonic animals than actual depth, for hauls at similar depths less than 300 miles from land gave more individuals and species than were obtained in hauls beyond 300 miles from land, except perhaps in the great Southern Ocean, where because of icebergs continental conditions are pushed far north of the Antarctic continent.

The greatest variety of animal life is probably to be met with in the shallow waters of

the tropical regions, especially in the neighbourhood of continental land and of coral reefs, but though the aggregate number of species may be less in temperate and polar coast waters than in tropical waters, this is counterbalanced by the extraordinary abundance of individuals in the cold waters towards the poles.

Littoral and Shallow-Water Benthos.—In considering the marine fauna of coastal regions it is usual to subdivide the area into zones according to the physical conditions and the materials covering the bottom. Thus in northern waters we may recognise a littoral zone extending from high-water mark down to about 20 fathoms, and a sub-littoral or shallow-water zone from about 20 fathoms down to about 100 fathoms. Beyond 100 fathoms we approach deep-sea conditions, the temperature and salinity becoming more and more uniform and the currents less marked, while the fauna at the same time becomes more and more uniform and more widely distributed both horizontally and vertically.

The littoral zone is subdivided, according to the bottom conditions, into areas and belts in different localities, such as the low-tide area, barnacle belt, fucoid belt, laminarian belt, zosteran belt, hard bottom, sandy bottom, muddy bottom, each characterised by its

own peculiar assemblage of fishes and invertebrate animals. On the bare rock, for instance, we find barnacles. mussels, limpets, and periwinkles; on the sea-weeds we find attached forms like sponges, hydroids, bryozoans, serpulids, actinians, and ascidians, along with caprellids, pycnogonids, nudibranchs, worms, starfishes, and brittlestars; on the sandy bottom we find burrowing forms like mussels, asterids, spatangids, worms, crustaceans, lancelets and sand-eels; on the hard bottom we find attached and non-attached forms like sponges, bryozoans, hydroids, corals, gorgonids, alcyonarians, ascidians, chitons and other molluscs, brachiopods, crustaceans, brittlestars, starfishes, echinids, crinoids, holothurians and worms; on the muddy bottom we find principally burrowing forms, including rhizopods, mussels, scaphopods, pennatulids, holothurians, crustaceans, actinians, worms and sponges.

In the shallow-water zone we find holothurians, starfishes, brittlestars, worms, brachiopods, mussels and other molluscs, crustaceans, corals, gorgonids, actinians, echinids, hydroids, bryozoans, ascidians and sponges. Just where the fine detrital matter from the land and shallow-water comes to rest on the sea-floor, a great feeding ground exists, where crustaceans and other animals pick up the

small particles of organic matter there settling on the bottom. This is called the *mud-line*, and on shores facing the great oceans its average depth is about 100 fathoms. This links on to a sort of artificial bottom in the open ocean, where a marked change in viscosity occurs, and a consequent change in the rate of fall of particles of organic detritus (see Chapter VII., p. 138).

Benthos of the Continental Slope.—The fauna living on the continental slopes beyond 100 fathoms is sometimes called the archibenthal fauna, but there is no clearly defined boundary between the archibenthal and abyssal areas. This archibenthal fauna in the North Atlantic is characterised by sea-urchins of the family Echinothuridæ, with flexible leather-like shells, and other echinids, crinoids, starfishes, brittle-stars, holothurians, actinians, pennatulids, free corals, alcyonarians, crustaceans, worms, molluscs, brachiopods and sponges. The fish-fauna living on the continental slope of the Eastern Atlantic was found during the "Michael Sars" Expedition to be very uniform all the way from the Faroe Islands to south of the Canaries, six species being common to these northern and southern localities (*Mora mora*, for example), thus differing from the fish-fauna of the continental shelf, the species of which are much more limited in their distribution.

The great economic fisheries of Northern Europe are limited to the continental shelf and continental slope, and the causes which lead to the fluctuations in these fisheries have been the subject of many recent investigations, especially by the Norwegians. There are indications that in some years the occurrence of abundant food at the time of the hatching of the eggs leads to a great development in the quantity and quality of the fish for a certain year, and the fish of that particular year dominate the character of the catches over a long series of years.

It is probable that the animal assemblages in tropical regions, as in northern waters, are distributed in somewhat similar zones of depth.

Deep-Sea Benthos.—We have stated that plants can only function within the photic zone, but still their dead remains, falling through the intermediate waters to the bottom, may on the way down and on the bottom furnish food for animals. It has been pointed out that a great change in the physical conditions, such as temperature, viscosity, penetration of light, takes place, especially in the tropics, at about 400 or 500 fathoms, and here many of these falling particles may be retarded in their descent, and may furnish at that level a rich feeding-ground for bathypelagic animals —a kind of artificial bottom, or extension of

the mud-line of the continental slopes. In the cold waters of the deep sea decomposition and putrefaction are slow processes, so that in the dead bodies of organisms there is still food for the scavengers, like holothurians, which eat the mud and in turn provide nourishment for the deep-sea carnivores.

Many characteristic deep-sea forms have long stalks lifting the bodies of the animals out of the mud, like some crinoids, pennatulids, alcyonarians, hydroids and bryozoans; others, like the pycnogonids and crustaceans, have long legs; others have well-developed tactile organs, like some crustaceans and fishes. Most of these forms are delicate in structure but of gigantic size when compared with their shallow-water allies. Those species which require calcium carbonate to form their skeletons—like the molluscs and corals—are feebly developed in the abyssal region. A selection of benthonic calcareous foraminifera is shown on Plate X.

Phosphorescent light evidently plays an important rôle in deep-sea life; cœlenterates like the alcyonarians have frequently been brought up from great depths in a light-giving condition. The colouring of deep-sea animals, mostly red and brown monotones without any patches of vivid colours, is doubtless correlated with the faint gleams of phosphorescent

light. It is probable that the animals giving out phosphorescent light are not evenly distributed throughout the deep sea, but are more or less localised and may be more abundant in some localities than in others, while certain regions may be utterly devoid of light, but this does not account for the great variations in the development of the eyes in deep-sea forms, in some of which the eyes are very large while in others the eyes are small or altogether wanting. Sometimes in the same haul of the trawl creatures with large eyes are brought up along with others that are totally blind.

It has been stated that the action of the digestive enzymes is retarded at low temperatures, and this action must therefore be very slow in the deep sea, so that the food requirements of deep-sea animals are less than those of the more active animals living in the warmer waters of the ocean.

The colonising of the deep sea seems to have been effected by successive migrations from the shallower reaches of the ocean, especially from the region of the mud-line (where it is supposed that the simplest forms of life originally appeared in pre-Cambrian times), but apparently more frequently from cold regions than from warm regions. If there were once a nearly universal warm

climate over the whole ocean, we cannot but suppose that the deep sea would be unfavourable for animal life owing to the want of circulation and atmospheric oxygen, but it is probable that the same or nearly allied species of benthonic animals were almost everywhere present in the shallow-water zones. When cooling at the poles set in, those animals with pelagic larvæ would be killed out or be forced to migrate towards the warmer tropics. By being able to limit the reproductive process to the summer season, some of these organisms with free-swimming larvæ have been able to live on in the temperate regions, but in the tropical and coral-reef regions we have the remnants of a once universally-distributed shallow-water fauna. With the disappearance of this shallow-water fauna from the polar regions its place would be occupied by the organisms from the deeper mud-line, very few of which have pelagic larvæ. In this way we may account for the similarity between the polar marine faunas and floras, the great abundance of individuals and the relatively few species in the polar areas when compared with the tropical area, as well as the greater likeness of the shallow-water polar animals to deep-sea species. From another point of view we might suppose rather cold water to be uni-

versal, the polar forms to be widely distributed, and the development generally direct; with an increase of heat at the equator there would be a great development of new genera and species having pelagic larval stages within the tropics, while polar organisms would evolve much more slowly.

Bathymetrical Distribution of the Benthos.—In discussing briefly the distribution of the benthos we may base our remarks on the results of the "Challenger" Expedition, deduced from dredgings and trawlings taken in deep and shallow water in all parts of the world under practically uniform conditions. These results are set forth in the table on page 182, indicating the number of species and genera of fishes and invertebrates (excluding protozoa) recorded in the "Challenger" Reports from the various dredging and trawling stations, arranged in zones of depth.

In this table the number of individual specimens from the shallow-water zone in depths less than 100 fathoms is left blank, because of the difficulty in arriving at an estimate of the numbers captured. In striking contrast to the abundance of individuals in shallow water is the fact that in deep water beyond 1000 fathoms the "Challenger" rarely took more than three or four specimens of any one species in each haul, and the

Zone of Depth	Number of Stations	Number of Individuals	Number of Species	Number of Genera	Ratio of Species to Genera	Species taken only in the zone referred to	
						Number	%
Less than 100 fathoms	70	—	4250	1440	2·93 : 1	3900	92
100 to 500 ,,	40	6000	1893	776	2·37 : 1	1408	74
500 to 1000 ,,	23	2000	631	363	1·67 : 1	406	64
1000 to 1500 ,,	25	2000	508	327	1·50 : 1	277	55
1500 to 2000 ,,	32	1250	412	272	1·45 : 1	249	60
2000 to 2500 ,,	32	820	262	184	1·36 : 1	165	63
More than 2500 ,,	25	600	161	127	1·17 : 1	96	60

number of species represented by single specimens is quite remarkable.

The sixth column in the table shows the large number of genera in relation to the number of species in the hauls from the deeper zones; in fact the ratio of genera to species rises in a most regular manner on proceeding into deeper and deeper water and farther and farther from land. In the deepest zone the species stand to the genera in the ratio of 5 to 4, while in the shallowest zone the ratio is 3 to 1. This relation might be explained by supposing that the deep sea was peopled by continuous migrations from the mud-line downwards and seawards at many different periods of time and from many different parts of the world.

In some instances the variety of animals brought up in the trawl and dredge from deep water was much greater than in similar hauls in shallow water. This was especially the case in the deep water of the Kerguelen region of the Southern Ocean, where the "Challenger" took eight hauls in depths between 1260 and 2600 fathoms yielding a total of 272 species, or an average of 34 species per haul; at one station in 1600 fathoms about 200 individuals belonging to 89 species were procured. This profusion of life in the Southern Ocean may be accounted for by

the continental conditions being pushed far from land towards the north by the presence of floating ice, probably also by the greater abundance of food falling to the bottom in this region, where pelagic organisms are frequently killed in large numbers through the mixing of surface currents from different sources and consequently varying greatly in temperature and salinity ; it may also be to some extent connected with the migration of benthonic animals towards the tropics.

As illustrating the restricted distribution of deep-water forms, it may be stated that out of the 272 species taken in the eight unusually productive hauls in the Kerguelen region just mentioned, not one species was common to the eight stations nor even to seven of the stations ; one species was taken at six stations, one species at five stations, two species were common to four stations, thirteen to three stations, and forty to two stations. At two neighbouring stations, about 120 miles apart, 145 species of metazoa were taken, and only twenty-two species were common to the two stations.

When trawlings and dredgings on different kinds of deposits are compared, it is seen that there is a relatively greater abundance of both individuals and species on the terrigenous deposits contiguous to continental land than

on the pelagic deposits farther removed from the land ; hauls with the trawl are almost always more productive than those with the dredge.

The forms recorded from the twenty-five "Challenger" hauls in depths exceeding 2500 fathoms (referred to in the table) include sponges, antipathids, actinians, corals, hydroids, crinoids, asterids, ophiurids, echinids, holothurians, annelids, cirripeds, pycnogonids, lamellibranchs, scaphopods, gasteropods, bryozoans, brachiopods, and tunicates (in addition to crustaceans and fishes, which cannot with certainty be regarded as having lived at the bottom, although it is believed that most of the Macruridæ are bottom fishes).

The majority of these deep-sea forms live by eating the superficial layers of the deposits, and by picking up the small organisms or organic particles falling from the surface, the struggle for food being apparently nearly as severe in the deep as in the shallow waters of the ocean. The idea that a universal and peculiar fauna of great antiquity overspreads the deep ocean-floor has not been supported by systematic investigations in deep water. Many deep-sea species are of gigantic size compared with their shallow-water allies ; those living in very deep water far from land present archaic characters, but the relict

fauna from remote geological periods which some naturalists once believed might be captured in the deep sea has yet to be discovered. It is true that *Discina* and other brachiopods, some of the irregular echinids, and some of the siliceous sponges represent ancient groups, but it is probable that among the shore and fresh-water forms there are representatives of faunas older than anything to be found in the deep sea.

Bipolarity.—As early as 1817 Sir James Clark Ross noted that several Arctic species occurred also in the Antarctic waters. Charles Darwin in his "Origin of Species" mentions J. D. Dana, J. Richardson and Joseph Hooker as having observed resemblances between the genera of the two polar regions, and Edward Forbes gives some examples of generic forms with two centres of dispersion, one in each hemisphere, separated by a tropical discontinuity.

In the first shallow-water dredgings in the southern temperate regions the "Challenger" naturalists were struck with the resemblance of the fauna to what they were accustomed to dredge off the coasts of Europe in similar depths. C. Wyville Thomson writes: "These shallow-water dredgings around Tristan da Cunha gave a great amount of material, the fauna being very much of the same character

as that of somewhat shallower water in the north. The species seem in many cases to be identical."

Observations similar to those above mentioned form the foundation for a belief in what has been called bipolarity in the distribution of marine organisms.

Cetacea.—Among the Cetacea, two families (Balænidæ and Balænopteridæ) appear to be limited to the cold and temperate seas of both hemispheres, and Sir William Turner states that *Balæna biscayensis* of the north and *B. australis* of the south are identical, and not present in the intermediate tropical zone.

Carnivora.—Among the eared seals allied species are found in the Antarctic and in the North Pacific, but not in the tropical waters; in the Atlantic, however, no eared seals occur in the northern hemisphere.

Fishes.—A. C. Günther states that the most striking character of the shore fish-fauna of the southern temperate zone is the re-appearance of types inhabiting the corresponding latitudes of the northern hemisphere and not found in the intervening tropical zone, and he mentions eleven species and twenty-nine genera as illustrating this character. The Salmonidæ are represented in the southern hemisphere by the fresh-water family Haplochitonidæ,

and the Dalliidæ by the Galaxiidæ. *Lycodes* is represented in the southern as well as in the northern hemisphere, and Günther thinks that the re-appearance of so specialised a genus in the Antarctic is remarkable. *Stomias boa* and *Halosauropsis macrochir* are apparently bipolar forms.

Tunicates.—H. Lohmann remarks on the striking relationship between Arctic and Antarctic forms of Appendicularians as compared with the relationship between polar forms and those of the tropics. At both poles there are closely related species of the genus *Oikopleura* and one identical species of the genus *Fritillaria* (*F. borealis*).

Echinoderms.—Hjalmar Théel writes that the shallow-water Holothurioidea of the far north and far south possess much the same features, and the distinguishing characters are often inconsiderable and possibly not of specific value. *Elpidia glacialis*, common in the North Atlantic and Arctic Oceans, was taken by the "Challenger" south of Australia. *Euphronides depressa* is also bipolar, and Edmond Perrier says that *Psolus squamatus* is present both in the northern and in the southern regions, while Clément Vaney says the Antarctic species (*Psolus segregatus*) is quite distinct. Alexander Agassiz was unable to distinguish the specimens of *Echinocardium*

flavescens collected at the Cape of Good Hope from the northern ones, and *Echinus norvegicus* is apparently bipolar. *Stichaster, Lophaster* and *Cribrella* amongst the asterids appear to be bipolar, as well as *Pontaster forcipatus* and *Dytaster exilis*, and *Ophioglypha bullata, Ophiocten hastatum* and *Ophiernus vallincola* amongst the ophiurids. Mortensen says that among littoral echinids there is no single bipolar species, nor even a bipolar genus.

Bryozoa.—Edith M. Pratt considers *Beania magellanica* and *Cellepora pustulata* bipolar species, as is also the gigantic form *Kinetoskias cyathus.*

Mollusca.—Georg Pfeffer states that there are numerous bipolar species amongst the molluscs, and W. E. Hoyle refers to the genus *Bathyteuthis* dredged by the "Challenger" in the Southern Ocean and recorded by A. E. Verrill from the North Atlantic. The pteropods *Limacina retroversa* and *L. helicina* have already been mentioned.

Pantopoda.—Karl Möbius says there are no bipolar species of pantopoda, but Willy Kükenthal points out that most species of the Southern Ocean are no more distinct from the North Atlantic species than the North Atlantic species of the same genus differ from one another.

Crustacea.—J. R. Henderson states that throughout the entire range of Crustacea there is no better illustration of bipolarity than that furnished by the Lithodidæ. *Munidopsis antonii* is recorded from the Southern Ocean and the south-east Pacific as well as from the north-west coast of Africa. *Palæmon squilla* of the North Sea closely approximates to *P. affinis*, though their habitats are the antipodes of each other. The genus *Crangon* appears to be bipolar. *Lophogaster typicus*, *Boreomysis scyphops*, and *Amblyops crozetii* are also bipolar, and C. Zimmer states that all the genera of Schizopods of the south temperate and cold zones, except two, are represented in the north. Amongst the Cumacea Zimmer says there are six or seven bipolar genera. D'Arcy W. Thompson says there are no bipolar isopods or amphipods, while Pfeffer maintains that numerous species amongst the amphipods are bipolar, like *Eurytenes gryllus* (= *Lysianassa magellanica*). According to W. Weltner the cirriped *Balanus porcatus* is bipolar. W. Giesbrecht enumerates six bipolar copepods, and G. S. Brady records *Harpacticus fulvus* from Europe and Kerguelen, remarking that Kerguelen is the locality which of all others has shown in its entomostracan fauna a close resemblance to that of Europe. *Calanus finmarchicus*, so common in the far north,

occurs also in the Antarctic, and the closely related *C. hyperboreus* is found near the Canaries and also near the Australian coasts.

Worms.—The nemertine *Carinoma* is bipolar, as also the littoral annelid *Terebellides stræmi.* E. Ehlers says that the Magellan coasts have twenty-one species of Polychætes which belong to the northern hemisphere, including *Nephthys longisetosa, Glycera americana, Scolecolepis vulgaris, Arenicola assimilis* and *Notomastus latericeus,* and Pratt gives about fourteen bipolar species. Amongst the Gephyrea *Priapulus caudatus* and *Phascolosoma margaritaceum* are bipolar. Two other southern species of Gephyrea have near relatives in the north, while of the southern genus *Echiurus* three species are Arctic. The pelagic chætognath *Sagitta* (*Krohnia*) *hamata* characteristic of the Norwegian Sea is also known from the far south.

Anthozoa.—The species of the genus *Alcyonium* are inhabitants of the temperate regions of all the three oceans. Of deep-sea Alcyonaria the sub-genus *Ceratocaulon* of the genus *Xenia* is bipolar, and so is the pennatulid *Umbellula encrinus.* Several genera of Actiniaria, *e.g. Bunodes, Edwardsia, Sagartia,* are bipolar.

Medusæ.—Otto Maas says that among the Medusæ a number of genera found in the Arctic

and Antarctic have no representatives in intermediate regions and there is a striking similarity in the character of the forms of the two regions. The siphonophor *Diphyes arctica* is bipolar.

Hydroids.—G. J. Allman states that no less than three British species of hydroids occur in both the northern and southern regions. *Perisiphonia filicula* is taken at the Azores and in the Australian region; the northern *Grammaria* is represented by three species from a comparatively narrow zone of southern latitude. *Sertularia operculata* is bipolar, and so is *Obelia geniculata*, a British hydroid taken in the vicinity of Kerguelen and the Falkland Islands. Clemens Hartlaub gives seventeen bipolar species of hydroids. Of the genera of the sub-Antarctic all except three are represented in the Arctic.

Sponges.—*Thenea grayi* from the South Australian region much resembles *Thenea muricata* of the Arctic regions.

Phytoplankton.—H. H. Gran states that of the seventeen species of Arctic oceanic diatoms eight occur also in the Antarctic and are wanting in the intermediate regions. In a private letter Gran writes that it is very difficult to decide from preserved material whether the Antarctic *Phæocystis* is identical with the Arctic *Phæocystis poucheti*; there

may be small differences to be detected only by carefully examining fresh samples. He says further that it is very interesting to see from the abundant material now available how some species, both of peridineans and diatoms, are represented in the Arctic and in the Antarctic by very similar but not quite identical forms.

From the foregoing observations it appears that:

(1) Species from the far north and far south, which some naturalists consider identical, are regarded by others as quite distinct, even although the differences are slight.

(2) Some authors look upon bipolarity as limited to identical species, while others apply the term to genera, families and orders.

(3) Some naturalists consider that there is a direct interchange of the so-called bipolar species by way of the cold deep waters of the tropics, or along the western coasts of continents where the temperature is lowered by cold currents and by upwelling.

(4) Some authors hold that, as there is a bipolarity in the chemical and physical conditions of the Arctic and Antarctic seas, these similar conditions give rise to what are called vicarious or parallel forms through convergence.

CHAPTER IX

MARINE DEPOSITS

Many thousands of samples of deposits have been obtained from the floor of the ocean, from all depths and in all latitudes. These have been carefully examined and compared, with the result that we can now form a very good general idea of the composition and distribution, both horizontally and with regard to depth, of the various types. It is true that the samples from the sounding tube are usually small in quantity, but these have very frequently been supplemented by very large quantities from the dredge and trawl. Our knowledge of these deposits is limited to the upper layers, for the sounding-tubes, trawls and dredges do not sink deeper than three feet, and generally only a few inches, into them.

The rocks of the land-surfaces are continually undergoing disintegration through atmospheric and other agencies. The products of these weathering processes are ultimately carried into the ocean by rivers and winds.

In the case of rivers the materials are either in solution or suspension, and the particles in suspension are for the most part deposited on the sea-floor whenever the salt and fresh water mix. It is well known that fine clayey matter in fresh water is at once precipitated upon the addition of a little salt. The detrital matters carried to the ocean by rivers are thus laid down near shore, the sands and gravels coming to rest in shallow water, and the finer clayey particles being deposited in deeper water.

The winds often carry the dust of deserts and of volcanic eruptions very great distances, and these can be detected in the deposits of deep water. Another volcanic product requires special mention, viz., pumice. This areolar substance, when it reaches the ocean either from rivers or volcanic outbursts, floats for a long time on the surface. The separate blocks are knocked against one another by the waves; small particles are broken off and fall to the bottom, and thus pumice is disseminated all over the sea-floor. The floating blocks are sometimes covered with cirripeds and other marine animals, but eventually they become water-logged and sink to the bottom, where they are ultimately decomposed into clay. Very many samples of these pumice stones have been dredged from

all depths and in all stages of decomposition. The materials of submarine eruptions are doubtless likewise present, but when of small size they are difficult to distinguish from those borne from land-surfaces. With the exception of certain secondary products formed *in situ*, these are the chief sources of the mineral constituents of marine deposits.

Next in importance to the above-mentioned mineral particles are the remains of organisms, and chiefly the shells and skeletons of those which secrete calcium carbonate. In shallow water the remains of calcareous algæ, of foraminifera, of corals, of molluscs, and of other marine invertebrates, form immense deposits, as for instance off coral reefs, where the percentage of calcium carbonate in the deposit often exceeds 90. These calcareous deposits are especially characteristic of the tropical regions, but the calcium carbonate shells are present in the deposits of all latitudes.

In deposits laid down on the floor of the ocean far from land it is not the shells of bottom-living (benthonic) organisms that predominate, but the shells of pelagic (planktonic) organisms, such as coccospheres, rhabdospheres, pelagic foraminifera, pteropods and other molluscs. In all but the very greatest depths these shells and skeletons accumulate,

and deposits of pteropod or globigerina ooze may contain over 80 per cent. of calcium carbonate, due to the presence of these pelagic shells.

Again, the siliceous frustules of diatoms, or the siliceous spicules and skeletons of radiolaria, may predominate in the deposits far from land. These have fallen to the bottom after the death of the organisms, just as in the case of the pteropods and pelagic foraminifera. But in marine deposits the siliceous spicules of sponges which lived on the bottom can also be detected.

The foregoing are then the principal constituents of marine deposits, but there are others which are not so abundant, such as small spherules of extra-terrestrial origin, and secondary products which have been formed *in situ* in the deposits, such as manganese-iron nodules, phosphatic, barytic and calcareous nodules, glauconite, and zeolitic crystals.

Some things that we should expect to find are extremely rare. The ordinary bones of fishes are seldom observed in the deposits, with the exception of teeth and otoliths, and the teeth of sharks, the earbones of whales and the dense beaks of ziphioid whales have been dredged in considerable numbers in some areas, but these are usually much corroded; the more areolar bones of whales are repre-

sented by only a few decomposing fragments.

These various inorganic and organic constituents of marine deposits are present in the samples in very different proportions, varying according to the distance from shore, the depth of water, the latitude, and the physical and chemical conditions of the surface waters. There is a wide distinction between a typical example of a globigerina ooze and one of red clay, or between a pteropod ooze and a diatom ooze, or a blue mud or green sand and a radiolarian ooze, but these varieties may merge by numerous gradations the one into the other.

Marine deposits might be classified in a great many ways, but after much consideration it has been found that a combined chemical and microscopical analysis gives the best results, and is the most useful for the geologist and the physical geographer. The microscope shows us that the calcium carbonate in a deposit consists mainly of dead shells of organisms, and we can tell whether these have lived on the surface of the sea or on the bottom, as well as the orders, genera and species to which they belong. In the same way the source of the siliceous remains of organisms and of the mineral particles can be determined. It is easy to determine the percentage of

calcium carbonate in the deposits by chemical analysis, and to indicate the nature of the organisms which yield this; the *residue* after the removal of the lime by weak acid is then subjected to microscopic analysis. The following is a sample description:—

S.S. "BRITANNIA," SOUNDING No. 75.—May 23, 1899, 39° 37′ N., 35° 23′ W., 2330 fathoms.

Globigerina Ooze, light brown or fawn colour, coherent, granular.

CALCIUM CARBONATE (62·5 per cent.), principally made up of shells of pelagic foraminifera (including *Orbulina universa, Globigerina inflata, bulloides, æquilateralis, rubra, conglobata, Pulvinulina micheliniana, canariensis, menardii*), with a few bottom-living foraminifera, echinid spines, ostracods, coccoliths, rhabdoliths, a few coccospheres.

RESIDUE (37·5 per cent.), brown:

Minerals (5 per cent.), mean diam. 0·1 mm., angular, pumice, volcanic glass, felspar, etc.

Siliceous organisms (2 per cent.), sponge spicules, radiolaria, arenaceous foraminifera.

Fine washings (30·5 per cent.), amorphous clayey matter, and minute mineral and siliceous particles.

The "fine washings" consist largely of hydrated decomposition-products of the type of clay, but include also varying proportions of very finely-divided undecomposed minerals, which cannot be separated from the clay except by chemical means.

From the point of view of their origin, marine deposits may be divided into two great classes: terrigenous and pelagic.

1. *Terrigenous Deposits.* These are mainly made up of detrital materials carried down from the land-surfaces or torn away from the coast-line and shallow water, together with the remains of organisms which live on the bottom in shallow water; quartz particles are highly characteristic of these deposits.

2. *Pelagic Deposits.* These are largely made up of the remains of calcareous and siliceous organisms which have lived in the surface waters of the ocean and have fallen to the bottom after death, and of an inorganic residue mostly composed of hydrous silicates of iron and alumina, derived chiefly from the disintegration of pumice and other volcanic fragments; particles of quartz-sand are rare, if not quite absent, except in regions affected by floating ice.

This scheme of classification is exhibited in the table on page 201, and the accompanying map (Plate XI.) shows the general distribution of the deposits over the floor of the ocean.

Other classifications have been suggested, but none of them appears to be an improvement upon, or to add to the clearness of, the one here adopted.

The *littoral deposits* found between tide-marks and the *shallow-water deposits* found between low-water mark and the 100-fathoms

MARINE DEPOSITS.

Littoral Deposits, between high & low water marks	Boulders, shingle, gravels, sands, muds, etc., derived from adjacent land	**Terrigenous Deposits** formed in deep and shallow water close to land masses
Shallow-Water Deposits, between low-water mark and 100 fathoms	Sands, gravels, muds, marls, derived from adjacent land, shores and shallow waters	
Deep-Sea Deposits, beyond 100 fathoms	Blue Mud Red Mud Green Mud Volcanic Mud Coral Mud	
	Globigerina Ooze Pteropod Ooze Diatom Ooze Red Clay Radiolarian Ooze	**Pelagic Deposits**, formed in deep water far removed from land

line cover about ten millions of square miles. Near shore these deposits consist of boulders, shingle, gravel, sands, with muds occasionally in sheltered positions; farther from shore they consist of gravels, sands, beds of living and dead shells, with muds in estuaries and depressions. The nature and composition of these shore and shallow-water deposits are largely determined by the structure and composition of the adjoining land-masses and

the character of the benthonic organisms living in the area: off volcanic islands there are volcanic gravels, sands and muds; off coral islands and reefs there are coral gravels, sands and muds; off continental coasts there are usually quartz gravels, quartz sands and marls.

In depths of about 100 fathoms (600 feet) the limit of wave action and of strong transporting currents is reached, and all the minute detrital matters come permanently to rest on the bottom at what has been called the *mud-line*. Beyond this depth the deposits become much more uniform in their physical characters and composition, although they still derive their general characteristics from the adjoining lands and coasts, but may frequently present a considerable admixture of the remains of pelagic organisms. All deposits laid down in water deeper than 100 fathoms are called *deep-sea deposits*, and to these we shall here limit our remarks.

Terrigenous Deposits.

1. *Blue Mud.*—This type is the one most frequently met with in the deeper waters surrounding continental land and in all enclosed and partially enclosed seas. The deposit is so called because it is usually of a blue or slate colour, with a thin upper red or brown laver where it has been in

contact with the superincumbent water. The colour of the upper layer is due to the presence of hydrated ferric oxide which, as the deposit accumulates, is partially transformed into ferrous sulphide and oxide in the presence of organic matter in the underlying layers; when dried the blue colour changes to grey or brown owing to oxidation of the iron sulphide. Sometimes the blue muds appear to be homogeneous, and may have the plasticity of true clay, but as a rule they are heterogeneous from the admixture of larger or smaller rock and shell fragments, and are rather earthy than clayey. Calcareous and siliceous remains belonging to plankton organisms vary greatly in amount according to position. Rock fragments and mineral particles may make up as much as 75 per cent. in some cases, the most characteristic species being quartz; the usual proportion of mineral particles is about one-fourth of the whole deposit. Amorphous clayey and muddy matters are always abundant, the average percentage being about 60, generally increasing in amount with greater distance from the land.

2. *Red Mud.*—This type is merely a local variety of blue mud found off the coast of Brazil in the Atlantic and off the coast of China in the Yellow Sea, the red-brown colour,

to which it owes its name, being due to the character of the sediment brought down by the large rivers in the vicinity. The ferric oxide is so abundant that it is apparently not all reduced to ferrous oxide, and iron sulphide does not accumulate in this type of deposit, hence the absence of the blue colour so prevalent in the deposits along other continental shores.

3. *Green Mud.*—This type may also be regarded as a variety of blue mud, characterised by the abundance of glauconite grains and glauconitic casts of calcareous organisms, which are usually of a greenish colour and impart a green tinge to the deposit, hence the name. Along high and bold coasts free from large rivers the deposition of fine detrital matter from the land is less abundant than in other positions, and the continental rock fragments and mineral particles are there longer exposed to the solvent action of sea-water, the products of their decomposition yielding the materials for the formation of the glauconite. In the shallower waters nearer the land the deposits contain less clayey matter and are more granular; they are then called *Green Sands.* This type is characteristically represented off the Atlantic and Pacific coasts of North America, off Japan, off Australia, and off the Cape of Good Hope,

and especially where cold and warm currents meet in the overlying surface water.

4. *Volcanic Mud.*—This type occurs around the oceanic islands of volcanic formation and along coasts where there are outcrops of volcanic rocks, the chief characteristic being the relative abundance of volcanic rock fragments and mineral particles. In the shallower waters near shore the deposits are coarser and contain less fine clayey matter, and are therefore called *Volcanic Sands.*

5. *Coral Mud.*—This deposit is found around the oceanic islands of coral formation and along coasts bordered by coral reefs, being characterised by the abundance of fragments of corals and other calcareous organisms living in the shallow waters and on the reefs. These fragments form a coarse sand or gravel near the reefs, and the deposit is then called *Coral Sand*, but with increasing depth and distance from the reefs the calcareous materials from the reefs become finer and finer in grain, forming frequently an impalpable coral mud, which passes at its seaward margin into pteropod or globigerina ooze.

Pelagic Deposits

6. *Globigerina Ooze.*—This type of deposit is second in importance only to the red clay, covering an extensive area throughout all the

great ocean basins. It is characterised by the abundance of the shells of pelagic foraminifera, and especially those belonging to the genus *Globigerina.* In tropical regions the foraminiferous shells may be visible to the naked eye, but usually the deposit appears to be homogeneous and of a fawn or greyish colour, sometimes forming an incoherent powder when dried. Besides foraminifera, many other calcareous remains may be found in the globigerina oozes. Some of them, like the pelagic molluscs and pelagic algæ, are derived from the surface waters; others, like echinoderms, worms, molluscs, corals and bryozoans, are the remains of bottom-living forms. The percentage of calcium carbonate in the globigerina oozes always exceeds 30, and rises in the purest samples to over 90, the average being usually between 60 and 70. The remains of pelagic foraminifera generally make up about one-half of the deposit, but the amount and the species vary according to latitude and depth. Within the tropics, in depths of 1500 and 2000 fathoms, the percentage of calcium carbonate due to the shells of pelagic foraminifera may reach 90, and nearly every known species may be represented in the deposits, but on proceeding towards the polar regions the percentage and the number of species in the deposits from similar depths

gradually diminish, the large thick-shelled tropical forms disappearing, until in the cold polar waters only one or two dwarfed forms are met with. The percentage of calcareous remains other than those of pelagic foraminifera in the globigerina oozes is also subject to great variation, being on the average about 10 or 12, while the remains of siliceous organisms usually make up 1 or 2 per cent., and mineral particles 3 or 4 per cent. The inorganic residue of a globigerina ooze resembles in all respects a red clay and has evidently a similar origin. This type of deposit covers an estimated area of about forty-eight millions of square miles, extending from lat 60° S. in the South Pacific to beyond lat. 70° N. in the Norwegian Sea; it is specially characteristic of the Atlantic Ocean, where it occurs at greater depths than in the other ocean-basins.

7. *Pteropod Ooze.*—This type may be regarded as a variety of globigerina ooze, characterised by the relatively greater abundance of the shells of pteropods and heteropods fallen from the surface waters. As these pelagic molluscs are to a large extent limited to the warmer waters of the ocean, pteropod oozes are found only in the tropical and subtropical regions, where they occur in less depths than globigerina ooze. This deposit covers an estimated area of about half a million square

miles, especially in the neighbourhood of coral reefs and on the summits and sides of submarine elevations far from land.

8. *Diatom Ooze.*—This type of deposit is distinguished by the abundance of the frustules of diatoms fallen from the surface waters, and occurs in those regions of the ocean where diatoms flourish luxuriantly, notably in the great Southern and Antarctic Oceans, but also along the northern border of the Pacific. When dry the diatom oozes are not unlike dirty flour and appear to be homogeneous, but when they occur in localities affected by floating icebergs there is usually an admixture of larger and smaller mineral particles, sometimes even boulders and rock fragments, with a small proportion of the remains of calcareous organisms, principally pelagic foraminifera belonging to one or two cold-water species. This type of deposit covers an estimated area of about ten millions of square miles, forming a nearly continuous band around the south polar regions, with a smaller area in the North Pacific.

9. *Red Clay.*—This type is probably the most characteristic and most widely distributed of all the deep-sea deposits. The basis of the deposit is hydrated silicate of alumina and iron, which usually makes up fully half the bulk, there being an admixture some-

times of calcareous and sometimes of siliceous remains, with volcanic mineral particles more or less decomposed, fragments of pumice, grains or nodules of manganese peroxide, earbones of whales, teeth of sharks, zeolitic crystals, etc. Calcareous remains are absent in the red clay from very deep water, but in less depths they may increase in abundance until the deposit merges gradually into globigerina ooze. In like manner siliceous remains may be absent from the red clays of certain regions, but in other localities radiolarian skeletons or diatom frustules may become so abundant that the deposit passes on the one hand into radiolarian ooze and on the other into diatom ooze. Of the inorganic admixtures in the red clays pumice is the most constant and most widely distributed; it occurs in fragments bigger than a man's head down to the most minute particles, recognisable only under the highest magnifying powers, and in all stages of decomposition—some almost unaltered, others surrounded by zones of alteration, and others so profoundly decomposed as to have lost nearly all trace of their original structure, and often enclosed within a thick coating of manganese peroxide. The crystalline minerals found in pumice, like sanidine, plagioclase, augite, etc., are also characteristic of red clays (as well as of globigerina and pteropod

oozes), along with volcanic glassy fragments more or less completely decomposed into palagonite. The origin of the red clay has been much discussed, but it is now generally admitted that the clayey matter is chiefly derived from the decomposition of volcanic particles *in situ*. The peroxides of iron and manganese are universally present in red clays, in the form of grains or coatings, or deposited concentrically around a nucleus as nodules of larger or smaller size. Among less frequent constituents found in the red clays are: small magnetic, metallic or chondritic, spherules, which are supposed to have formed part of the tails of meteorites and to have fallen from interstellar space; zeolitic crystals formed *in situ* from the decomposition-products of basic volcanic débris; wind-borne particles from desert regions and in some areas ice-borne rock-fragments and minerals from polar regions; and volcanic ashes derived from both subaerial and submarine eruptions. Traces of many of the rarer metals have been detected in the manganese nodules from the red clay areas. The proportion and size of the mineral particles in the red clays vary greatly, but as a general rule (if we except the nodules formed *in situ*) they are very small, the larger ones usually showing traces of profound alteration. The

great bulk of the red clays consists of what are called " fine washings," largely made up of clayey matter, intimately mixed with oxides of iron and manganese and the smallest comminuted fragments of the other constituents found in the same deposits. Red clay covers an area estimated at about fifty millions of square miles. In the Pacific Ocean it attains its maximum development, but it is also present in the Indian and Atlantic Oceans. In the Atlantic the red clays are usually of a lighter shade of red than in the Indian and Pacific, where they very frequently assume a dark chocolate-brown colour due to the large proportion of grains of manganese peroxide.

10. *Radiolarian Ooze.*—This type is merely a variety of red clay, in which the skeletons of radiolaria and the frustules of the large diatom, *Coscinodiscus rex,* fallen from the surface waters, become so abundant as to form an appreciable proportion of the deposit. Otherwise the mineral particles (pumice and volcanic glass more or less completely transformed into palagonite, associated with manganese peroxide in grains and nodules) and other constituents are similar to those in the red clays. It will be seen from the map that this type of deposit is limited to those regions of the ocean where the surface conditions are

favourable for the development of radiolarians in great profusion, as in certain parts of the Pacific and Indian Oceans, where radiolarian oozes cover an area estimated at about two millions of square miles; in the Atlantic this type is quite unknown.

Murray and Irvine have shown experimentally that the remains of siliceous organisms are removed in solution, like those of calcareous organisms, and the reason why they are found in greater depths and more abundantly in some deposits than in others depends upon their greater or less abundance in the surface waters.

Generally speaking, in the deepest regions of the ocean calcium carbonate is either absent or present only in very small percentages, while occasionally there are considerable numbers of radiolarian and diatom remains (red clays and radiolarian oozes). In the medium depths of the ocean, especially far from land, the dead shells of the pelagic calcareous organisms (and in some regions the siliceous organisms also) play a predominant rôle in the formation of the deposits (pteropod ooze, globigerina ooze, and diatom ooze). On the continental slopes and in all enclosed seas there is usually an admixture of pelagic organisms in the deposits with the finer detrital matters

from the land and shallow water, but in some of the muds there is an almost entire absence of the remains of pelagic calcareous organisms (blue mud, red mud, green mud, volcanic mud, and coral mud). On the continental shelf the deposits are principally made up of the larger fragments derived from the land along with the remains of bottom-living organisms (quartz and coral sands, gravels, marls, etc.).

Stratification.—In many deposit-samples brought up in the sounding-tube after it has penetrated deeply into the bottom distinct evidences of stratification may be discerned, especially in terrigenous deposits; indeed, the opinion has been expressed that stratification is the rule, and where it is not observed the sounding-tube has not penetrated through the uppermost layer. Sometimes globigerina ooze overlies blue mud, diatom ooze, or red clay, sometimes diatom ooze overlies blue mud, and sometimes red clay overlies globigerina ooze; the last-mentioned arrangement seems to point to subsidence of the sea-floor. More frequently differences in colour, but no great differences in composition, are met with in the same deposit-type.

Organic Matter.—The rôle played by organic matter in the ocean is a very complex and important one, leading to continual and extensive changes in the internal constitution

of the sea-water salts and of the materials in suspension in sea-water and lying on the floor of the ocean, the intensity of these changes varying with the temperature and other conditions. In nearly all deep-sea deposits traces of albuminoid organic matters can be detected, and the deep-sea animals on the sea-floor live by eating the superficial layers of the deposits, finding sufficient organic material therein to support life. The decomposition of organic matter in the deposits is associated with the formation of glauconite and of phosphatic grains and nodules, and other like re-formations, such as reduction of oxides in blue mud.

Calcium Carbonate.—Calcium carbonate is present in sea-water in the forms of the normal carbonate and of the bicarbonate. The normal carbonate is very slightly soluble, average sea-water containing only 0·12 part per thousand. Under certain conditions, however, the quantity may be much increased. Thus sea-water saturated with calcium carbonate, that is containing the normal amount which it will dissolve at a given temperature, may, after remaining for a certain period in contact with the same substance in a state of exceedingly fine division, take up as much as 0·65 part per thousand. The solution is then said to be super-saturated, and after

standing for some time the excess will be deposited as crystalline calcium carbonate, thus causing the filling-up of the interstices of massive corals with crystalline carbonate. Free carbonic acid in sea-water increases the solubility of calcium carbonate, calcium bicarbonate being formed, but this salt is much more soluble than the normal carbonate and very unstable, so that it may be broken up into normal carbonate and free carbonic acid by evaporation and by rise of temperature.

Part of the calcium carbonate in sea-water is withdrawn by lime-secreting organisms to form shell and coral. Generally speaking, organisms secrete calcium carbonate much more abundantly and rapidly in warm than in cold water. In the Arctic and Antarctic Oceans and in the deep sea, where the temperature approaches the freezing point of fresh water, there are no great accumulations of calcium carbonate due to secretion by benthonic organisms, and the calcareous shells and skeletons secreted by pelagic organisms are thin and fragile. On the other hand, the most abundant secretion of calcium carbonate, both by benthonic and planktonic organisms, occurs in tropical and sub-tropical waters. Thus coral reefs are developed in greatest perfection in those ocean waters where the temperature is highest and the annual range

least; many species of pteropods, heteropods, gasteropods, foraminifera and calcareous algæ (coccospheres and rhabdospheres) flourish in the surface waters of tropical regions, and the largest and thickest-shelled specimens are found in the regions of the equatorial calms

During the "Challenger" Expedition an attempt was made by the writer to estimate the quantity of calcium carbonate in this form in tropical surface waters. A tow-net with an opening a foot in diameter was dragged for as nearly as possible half a mile through the water, and the shells collected were boiled in caustic potash, washed, dried and weighed, the mean of four experiments giving 2·545 grams. If the calcareous organisms were as abundant at all depths down to 100 fathoms as they were in the track followed by the tow-net, there would be sixteen tons of calcium carbonate in this form in a mass of tropical oceanic water one square mile in area by 100 fathoms in depth.

Proceeding polewards from the tropics these calcareous organisms become smaller and many varieties die out, until in the cold surface waters of the Arctic and Antarctic regions only one or two thin-shelled species of pteropods, and one or two dwarfed species of foraminifera, occur. In like manner much less calcium carbonate is secreted in the cold

deep waters of tropical regions than in the warm surface waters, the calcareous structures becoming less massive with increasing depth.

Although lime-secreting organisms are so abundant in tropical surface waters, their shells and skeletons are rare or entirely absent from large areas of the ocean-floor in the greatest depths. Pteropod ooze for instance is limited to the comparatively shallow depths of the warmer oceans, and yet it has been shown by hundreds of observations that pteropods and heteropods are as abundant at the surface over areas where not a trace of their shells can be detected in the bottom-deposits as over areas where they have accumulated to such an extent as to form a pteropod ooze. The same holds good with reference to the shells of pelagic foraminifera and calcareous pelagic algæ. When a series of deposits is examined from the same tropical area, but from different depths, it is found that in depths of between say 500 and 1000 fathoms nearly every species of calcareous shell taken by the tow-nets in the surface waters may be observed in the deposit at the bottom. In greater depths—say between 1000 and 2000 fathoms—all the thinner and more delicate shells have disappeared from the deposit, especially the pteropod, heteropod, and the smaller and more

fragile of the foraminifera shells. In still greater depths—say between 2000 and 3000 fathoms—only the heavier and more massive foraminifera shells are present in the deposits, and many of these are corroded and in process of decomposition. In the greatest depths—between 3000 and 5000 fathoms—it is often difficult to find even a trace of these pelagic shells.

The shells must be removed by solution, either while falling through the water to the greater depths or shortly after reaching the bottom. As soon as a lime-secreting organism dies in the surface waters, it commences to fall towards the bottom, and its shell is exposed to solution from the solvent action of the sea-water and of the carbonic acid present in the sea-water, produced perhaps by the decomposition of its own body. The great majority of the shells are, however, only partially removed during the first few hundred fathoms, and therefore reach the bottom at the lesser depths and accumulate there. More of the shells may be dissolved as they lie at the bottom, but in depths of a few hundreds of fathoms they are soon covered up by the fall of other shells, and thus protected to some extent from further solution. Another point is that, since sea-water can take up only a relatively small quantity of calcium carbonate before

being saturated, the water in contact with a calcareous deposit must be very near saturation-point and has therefore less solvent power. Solution is, however, apparently more active beyond 2000 fathoms, which may be due to the lower temperature, to the increased pressure, and to the greater abundance of carbonic acid in the water. In areas occupied by massive warm surface currents, where lime-secreting organisms are more abundant than elsewhere, the shells accumulate on the bottom at greater depths than usual, as is also the case in areas where warm and cold currents meet at the surface, where there is reason to believe that organisms are killed in greater numbers than elsewhere by the sudden changes of temperature.

In those parts of the ocean-floor covered by chocolate-coloured red clays, characterised by the abundance of manganese in nodules and grains, as in the Central Pacific, it seems as though the calcareous shells were removed from the deposit at less depths than usual, possibly by some hypogene action. Thus red clays are found in the Pacific in depths at which globigerina oozes occur in the Atlantic.

The amount of calcium carbonate secreted by organisms from sea-water must be enormous, and since only a comparatively small quantity is present in solution, lime-secreting

organisms must be able to utilise the other salts of calcium present in sea-water in the formation of the carbonate. Wherever effete animal matter is thrown into the sea, or wherever animal structures are undergoing decay in the ocean, decomposition-products, many of them of a complex constitution, pass into solution. In the presence of sea-water salts these products give rise to many reactions, the formation of ammoniacal salts always taking place to a greater or less extent. Carbonate of ammonia, arising from the decomposition of animal products, in presence of the sulphate of lime in sea-water becomes carbonate of lime and sulphate of ammonia. The whole of the lime salts in sea-water may be changed by this reaction into carbonate, and so presented to the lime-secreting organisms in a form suitable for their requirements. Murray and Irvine's well-known experiments with crabs and hens seem to point conclusively to this origin of calcareous structures in the living animal. The temperature of the water is of great importance in this reaction, which is retarded in cold water but proceeds with great rapidity in warm water. This probably explains the great development of massive calcareous structures in the coral reef regions, which are also the regions of highest and most uniform temperature in the

ocean, and also the great extension of lime-secreting pelagic organisms in the tropical surface currents flowing northwards and southwards from the equator. Solution of calcium carbonate is continually going on in some parts of a coral reef, while great deposition by living organisms is proceeding in others. In this way it is believed that the characteristic form and features of barrier reefs and atolls can be explained without calling in a subsidence of the sea-floor, which for a long time was considered an essential condition for the formation of barrier reefs and atolls. On the whole, the lime of the lithosphere is, by the processes just indicated, being accumulated towards the equator at the present time.

Phosphatic Nodules.—In certain regions near land, where surface currents from different sources alternate with the seasons, phosphatic concretions, largely made up of phosphate of lime derived from the decomposition of organic remains, are accumulating in considerable quantities on the underlying sea-floor.

Glauconite.—This is a silicate of potassium and iron, the constituents of which are derived from the decomposition of continental rocks and minerals. It is generally deposited in the internal chambers of foraminifera and other

calcareous organisms, and revealed in the deposits after treatment with dilute acid as greenish casts and rounded green grains, sometimes in such abundance that the deposits are called green muds or green sands.

Barium Nodules.—Small quantities of sulphate of barium have been detected in many marine deposits, and off the coast of India small spherical nodules containing 75 per cent. of barium sulphate have been dredged in 675 fathoms of water.

Manganese Nodules.—The peroxides of manganese and iron in the form of small grains are widely distributed throughout all deep-sea deposits, and nodules of various sizes occur in great abundance in certain red clay areas, especially of the Central Pacific, concreted around various nuclei such as sharks' teeth, cetacean earbones, fragments of volcanic rocks and glasses, pumice, etc.

Teeth of Sharks and Earbones of Whales.—Sharks' teeth are dredged in considerable numbers sometimes in very deep water, more especially in the Central Pacific, but it is merely the external shell (the hard dentine or enamel) that is preserved, the internal portion and base having been removed. These teeth are all impregnated and more or less thickly covered by manganese peroxide. The dense earbones and beaks of whales have been

dredged in the same regions as the sharks' teeth, impregnated and coated with manganese in a similar manner. Such remains of sharks and whales have evidently lain for long periods of time exposed to the solvent action of the sea-water, as many of them belong to tertiary and extinct species (see Plate XII.).

Cosmic Spherules.—The materials derived from extra-terrestrial regions, though interesting on account of their origin, are of small size and comparatively rare. They consist of (1) black magnetic spherules frequently with metallic nuclei, and (2) brown chondritic spherules with crystalline structure, and are supposed to have formed at one time part of the tails of meteorites. They are usually found in the deposits from very deep water, especially from some of the red clay areas, doubtless because few other materials there reach the bottom to cover them up (see Plate XII.).

Zeolites.—Zeolites are represented in the deposits of very deep water, especially in the red clays of the Central Pacific, by phillipsite, a silicate of calcium and aluminium, the constituents of which are derived from the decomposition of volcanic materials. It occurs in crystalline form: as isolated elongated crystals, twins, and aggregates of different

numbers of crystals assuming a spherical form of small size (see Plate XII.).

Rate of Deposition.—From observations made by telegraph cable engineers in the North Atlantic it is believed that globigerina ooze accumulates, in lat. 50° N., long. 30° W., at the rate of an inch in about ten years in 2300 fathoms, and in lat. 3° N., long. 30° W., at a somewhat more rapid rate in 1900 fathoms, while recent investigations indicate that in certain positions deposition may be hindered even in depths exceeding 1000 fathoms by tidal currents. Theoretically it may be assumed that terrigenous deposits accumulate much more rapidly than pelagic deposits, and this is confirmed by observations, a maximum rate of deposition being found near land, especially off the mouths of large rivers, and a minimum rate in those red clay areas farthest removed from continental land in very deep water.

Radio-active Matter.—From a study of some representative samples of deep-sea deposits supplied by the writer, J. Joly has found that the radium-content is much higher in deep-sea deposits than in terrestrial rocks, and that red clays and radiolarian oozes from very deep water contain much more adium than the calcareous pteropod and globigerina oozes from shallower depths. It

seems that the amount of radio-active substances, of manganese nodules, of whales' ear-bones, of sharks' teeth, of cosmic spherules and of zeolitic crystals is greatest where there is every reason to believe that the deposition of material on the sea-floor is at a minimum. The presence of lead (which is supposed to be the ultimate disintegration-product of uranium) in J. Gibson's analysis of manganese nodules from the red clay in the centre of the Pacific is in this connection significant.

CHAPTER X

THE GEOSPHERES

The earth is the only planet of our solar system having oceans on its rocky surface. Mars and the moon had apparently at one time large bodies of water on their surfaces, but these seem now to have disappeared. The same fate is possibly in store for our oceans. We look back on a past when the crust of the earth was in a molten condition with a temperature of 400° F., when what is now the water of the ocean existed as water-vapour in the atmosphere. We can imagine a future when the waters of the ocean will, because of the low temperature, have become solid rock, and over this will roll an ocean of liquid air about forty feet in depth. The earth is at present in the terraqueous phase of its evolution, that is to say, its surface is occupied by continents and islands, oceans, seas, lakes and rivers.

If we regard our earth as it is swung in space at the present time, we may see, with the mind's eye, that it is composed of concentric

spheres or shells of matter in the gaseous, liquid, and solid or "trans-solid" states. These have been called Geospheres, viz., the atmosphere, the hydrosphere, the lithosphere, the biosphere, the tektosphere, and the great centrosphere which makes up by far the greatest mass and volume of the globe. To the interaction of these geospheres, and to energy derived from internal and external sources, can be referred all the existing superficial phenomena of the planet.

The *atmosphere* forms the outer shell, and is chiefly composed of a mixture of oxygen and nitrogen, together with water-vapour, carbonic acid, and rarer gases like argon, neon, etc. Dust particles may also be considered as a constant constituent of the atmosphere. A complete mixture of the oxygen and nitrogen takes place throughout the whole atmospheric envelope according to the known laws of gaseous diffusion, but the equilibrium of the aqueous vapour is continually disturbed by the ceaseless processes of condensation and evaporation, which vary in amount with every change of temperature and pressure. When, with a lowering of the temperature, water-vapour becomes rain or ice or snow, great movements are brought about in the atmosphere, warm, moist, and light air generally ascending in cyclonic areas, and

cool, dry, and heavy air descending in anti-cyclonic areas. The gases of the atmosphere penetrate the soil and rocky crust, and are absorbed at the surface of the ocean, being carried to the greatest depths by the circulation of ocean waters.

The *hydrosphere* has been specially considered in the preceding chapters. It is mostly made up of the waters of the ocean, and lakes and rivers are also included. Some of the water may be in the solid and gaseous states, as ice, snow, hail and the water-vapour of the atmosphere. Water likewise penetrates deeply into the rocky crust, where it produces the hydration of minerals, and water forms a large part of the biosphere.

The *biosphere*: Wherever water is present, or rather wherever water, air, and earth are in contact and commingle, life in some of its many forms can usually be detected. Indeed the whole planet may be regarded as clothed with a mantle of living matter. If we choose to give our imagination a little more rein, then we may say that within the biosphere a sphere of reason and intelligence has been evolved in man, who attempts to interpret and explain the cosmos; this may be called the *psychosphere*.

The *lithosphere* consists of the hard rocky crust with which we are familiar on the con-

tinents and islands and on the floor of the ocean. We know the continental rocks by borings and mines to the depth of several thousand feet, but that portion (three-fourths of the whole) on which the ocean rests is known by actual observation only to the depth of a few feet, since our sounding-tubes and dredges rarely penetrate deeper than three feet into the marine deposits. The rocks of the lithosphere are heterogeneous in structure and composition so far as they are open to direct observation: at some places there are great extrusions of both acid and basic lavas, at other places there are granites and hornblendic and other gneisses, as well as vast strata of sandstones and limestones, and in the preceding chapter it is shown that marine deposits are heterogeneous.

The deep-sea soundings recorded during the last half-century now permit us to draw some wide general conclusions concerning the topography and composition of the external surface of the rocky crust. The knowledge we have acquired, relating to the depth of the ocean below sea-level and the height of the dry land above sea-level, shows that the surface of the lithosphere, which has been calculated to have an area of about 197 millions of English square miles, may be regarded as consisting of:—

(1) A great elevated plain, comprising the surface of the continents, estimated to have an average height of about 2250 feet above sea-level and to cover an area of about 57 millions of square miles: add to this the continental shelf, extending from the shore-line to the 100-fathoms line and covering an area of about 10 millions of square miles, and we have what may be called the *continental area*, occupying in all about 67 millions of square miles, or about one-third of the superficial area of the globe;

(2) a connecting slope, from the 100-fathoms line down to a depth of about 1700 fathoms (the mean sphere level), which is called *the continental slope*, occupying about 30 millions of square miles, or about one-sixth of the superficial area of the globe; and

(3) a great submerged plain—the floor of the ocean-basins—estimated to have an average depth of about 15,000 feet below sea-level, which is called *the abyssal area*, occupying about 100 millions of square miles, or fully one-half of the superficial area of the globe.

The upper surface of the continental plain stands, then, on an average about two and a half miles above the submerged plain that forms the floor of the ocean. From this great submerged region volcanic cones frequently rise above the surface of the

ocean, forming oceanic islands. Sometimes they are capped at the sea-surface by coral reefs in the form of atolls, or they may not rise to the surface, and then form submerged banks covered with a white mantle of living and dead calcium-carbonate organisms.

Along the sides of these great cones and between them, as well as on the tops of submerged cones, there is evidence of marine currents, probably due to the tidal wave, but with this exception there is no evidence of transport or erosion over the surface of the great abyssal plain; it is essentially an area of deposition. The sun's rays never reach this deeply submerged part of the lithosphere, and the temperature over the whole of the deep ocean-floor never rises higher than two or three degrees above the freezing point of fresh water.

If we put our finger on a map of the South Pacific half way between South America and Australia, we indicate an area farther removed from continental land than any other area on the globe. If a successful trawling be made in this area at a depth of over 2400 fathoms, the net will contain several hundreds of sharks' teeth (*Carcharodon, Oxyrhina, Lamna*) and dozens of earbones of whales, a few beaks of ziphioid whales and a few fragments of the more areolar bones of

cetaceans. All these organic remains will be deeply impregnated with the peroxide of manganese, and some of the earbones and sharks' teeth will be surrounded by concentric layers of black manganese nearly an inch in thickness. Some of the teeth and earbones belong to extinct species. Besides these there will be hundreds of other manganese nodules formed around palagonitic and other volcanic fragments. These will all be embedded in a dark brown clay, consisting of hydrated silicate of alumina and oxides of iron and manganese, and this clay will contain crystals of phillipsite in the form of balls, aggregates varying in number, twins, or single individuals. Lastly a magnet will draw from the clay a good number of magnetic spherules, believed to be of cosmic origin. Some have a black coating which covers a metallic nucleus of iron and nickel. Others, brown in colour and crystalline in structure, are called "chondres," and have hitherto only been found in meteorites.

This is a very remarkable assemblage of organic and inorganic materials. How is their presence at this spot and depth to be explained? The depth is too great for more than a few of the calcareous surface shells to reach the bottom, and there are very few remains of siliceous organisms in the deposit.

Ordinary detritus from the continents cannot be detected, while volcanic ash and pumice are present.

It seems evident that very little of the ordinary deposit-forming materials reach these deep red-clay areas, and that in consequence rare and unusual constituents come into prominence. The materials have all been for a very long time exposed to the action of sea-water. The manganese nodules and zeolites are secondary products formed *in situ*. The volcanic materials are all profoundly altered or disintegrated ; only the hard dentine of the sharks' teeth and only the densest of the cetacean bones remain. The cosmic spherules have fallen from interstellar space, and they are found more abundantly here than elsewhere simply because they are not covered up by any large amount of other materials. In an area such as has just been pictured the rate of deposition is at a minimum—a foot of deposit may not have been laid down since the early Tertiary period. All the materials we have mentioned may occasionally be met with in the other varieties of deep-sea deposits, but never in such abundance as on the red-clay areas. The composition of these red clays warrants the belief that they would, when consolidated, form rock with a relatively high specific gravity. The animals dredged

from such a typical red-clay deposit remote from continental shores are few in number, although they show archaic characters (*Discina* and other brachiopods, *Stephanoscyphus*, crinoids, siliceous sponges, etc.). If there be what may be called desert areas on the sea-floor, then they are certainly situated in these red-clay regions.

Another peculiarity of the red clays is the absence of quartz particles; indeed, all the truly pelagic deposits far from land contain extremely few traces of quartz-sand except where the ocean is affected by floating ice. This is a very important matter, for in all the terrigenous deposits laid down in deep or shallow water near the continents quartz is the most characteristic constitutent, making up frequently more than half of the deposit. Indeed, the analogues of the now-forming terrigenous deposits are to be found in all geological periods, whereas no analogues can be found of the truly pelagic deposits now being laid down on the floor of the ocean, which cover fully one-half of the surface of the earth. If these terrigenous deposits have been continually pushed up on the continental areas or thrust under them in a more or less viscous or plastic condition ever since the first precipitation of rain on the globe, then this would tend to make

the continental areas of the lithosphere lighter than the sub-oceanic areas, because of the lower specific gravity of these siliceous depo·its.

If the surface of the earth was originally a molten mass, we may assume that all the silica (SiO_2) was originally in combination with bases, and that the primeval rocks were basic rather than acid in composition. With the first precipitation of rain on this primeval crust, many substances were doubtless washed down from the atmosphere, and many new compounds were formed. When the surface cooled and the primeval crust formed, the processes which we now see in operation would soon be established. As at the present time, carbonic acid being in aqueous solution would attack the felspars and other silicates, carry the bases away in solution, and a considerable part of the silica would be left on the continents to form vein quartz. When this rock was again melted and re-formed, it would contain more silica than the original one, and would be more acid in composition. With a repetition of this process the rocks on the continents would become on the whole more and more acid—would approach the composition of granite and gneiss.

The processes here indicated would ultimately result in a great accumulation of

silica on the continental areas, and consequently the continents would become the lighter portions of the external crust and necessarily stand at a higher level than the floor of the oceans. In this way through the action of forces which we can now observe in operation the surface features of the external crust appear to have been slowly developed.

We have seen as a result of the study of deep-sea soundings that the continental blocks of the lithosphere stand on the whole about two and a half miles above the sub-oceanic blocks, and physicists generally believe, for mechanical reasons, that these must be the lighter portions of the lithosphere, or they would not be elevated above the depressed portions; and many observations go to confirm this view. In a paper discussing the recent observations on the measurement of the intensity of gravity on the ocean, G. W. Littlehales says: "Concerning the dispute as to whether the oceans have always had the same general extent and positions since the waters were gathered together, or as to whether, by alternate rising and sinking of the earth's crust, oceans and continents have successively occupied the same areas, the deciding stroke appears to have been delivered in favour of the permanence of the ocean basins, on account of the extreme improbability that

there could be such a shifting of materials in the depths of the earth's crust as would cause the sub-oceanic heaviness to give place to the sub-continental lightness which has been found to subsist."

Should this result be accepted as clearly established, then what is to be said about the sunken continents and land-bridges which have been constructed across ocean-basins by biologists and geologists to explain the distribution of rock formations and of fossil and living organisms? The western mountains of Europe and the eastern mountains of the United States are supposed to be fragments of the great mountain ranges of "Atlantis," now buried beneath the floor of the North Atlantic. Again, portions of South America, of Africa, and of India are believed to be fragments of "Gondwanaland," now buried beneath the submerged floor of the great Southern Ocean. The study of ocean-depths and ocean-deposits does not seem in any way to support the view that continental land has disappeared beneath the floor of the ocean in the manner just indicated.

It is no doubt very difficult to account for the distribution of rocks, of fossils, and of living creatures on the existing continents and islands, but this distribution is better interpreted by the north polar theory of the origin

of land animals, and their slow and interrupted spread along the three great south-reaching continental tongues of land, than by great hypothetical land-bridges. It is in like manner difficult to account for the evidences of coral reefs in the polar areas and of glacial periods towards the equator, but it seems easier, from a physical point of view, to assume a shifting of the poles, a second rotation of the earth, or even a change in the position of the continental blocks relatively to each other as well as in their geographical position on the surface of the globe (possibly after the separation of the moon), than to accept the theory that whole continents have completely disappeared below the bed of the existing oceans.

The existing superficial layers of the lithosphere, both on the continents and beneath the oceans, appear to be parcelled out into great earth-blocks, separated from each other by faults and fissure-lines, along which volcanic action and gaseous emanations take place, and through which massive outflows of molten matter occur, but there seems little evidence to show that magmas have other than a quite local extent. On the whole these volcanic materials appear to be lighter and more acid in composition over the continental areas, and heavier and more basic over the sub-oceanic areas. The continental

earth-blocks apparently tend to become elevated, whereas what information we have about the floor of the ocean indicates that there the similar earth-blocks tend on the whole to subside. It is not likely that faults and fissures extend deep into the lithosphere; they must be regarded rather as relatively superficial phenomena.

The *tektosphere.*—A great many recent seismic, geodetic, gravity, and geological researches go to confirm what had long been indicated, that there is, at a depth of somewhere about thirty miles beneath the surface of the earth, a more or less heterogeneous and stony layer which, under varying conditions of temperature and pressure, becomes solid, viscous, or even liquid. It is to this layer, interposed between the relatively cold, solid, heterogeneous, acid lithosphere and the highly heated, solid, relatively homogeneous, basic and metallic centrosphere, that the writer, a good many years ago, gave the name of *tektosphere.* This plastic layer is believed to be the region in which isostatic adjustment and compensation take place, and it apparently lies at a deeper level under the continents, composed of lighter, more acid, and less fusible materials, than under the ocean's floor, where the rocky materials are apparently heavier, more basic, and more fusible. We may

suppose that when, through loss of heat, the great deep-seated centrosphere suffers contraction, the outer lithosphere is adjusted to the diminished volume through flow-changes in the rocks of the tektosphere, this flow being generally in the direction of the continental masses, the general tendency being slowly to elevate the continental earth-blocks and relatively to depress the sub-oceanic earth-blocks. The rocky materials of the tektosphere are probably more homogeneous than those of the overlying lithosphere, but not so homogeneous as the underlying more or less metallic centrosphere.

The *centrosphere.*—It is generally admitted that the earth as a whole is five and a half times heavier than water, or about two and a half times heavier than the materials of the rocky crust—such as granite and limestone—with which we are familiar. From this it is inferred that the great massive core, or *centrosphere*, is very largely composed of iron, with gold, platinum, and other heavy metals. This view is corroborated by the fact that the molten lavas, protruded at the surface of the globe and believed to have a very deep-seated origin, are more basic in composition than those regarded as having a more superficial origin. Again, the ores of gold, silver, tin, and other heavy metals, which are found in

veinstones of fissures and faults, are for many reasons regarded as having largely originated in gaseous emanations from very deep-seated positions. Further, the meteorites which fall on the earth from extra-terrestrial spaces are for the most part made up of iron, nickel, and the heavier metals, thus indicating, as does also spectrum analysis, the predominant composition of celestial bodies. The revolution of planets round their axes and round the sun, the planes of their orbits, and the revolution of satellites around primaries, are all remarkable features of the solar system which point likewise to a common origin of the bodies it contains.

There are many reasons for regarding the whole of the interior of the earth, beyond a depth of thirty or thirty-five miles from the surface, as having a very homogeneous composition and structure, whether we adopt the nebular or the meteoric and planetesimal hypothesis. If this great centrosphere be not solid, it behaves at all events as if it were as rigid as steel, and towards the centre, being largely composed of iron, it has probably a density of about 8. This view is supported by the manner in which earthquake vibrations are transmitted through the great central mass of the earth. Temperature observations in deep mines and

borings show that the temperature of the superficial crust increases with depth, the increase ranging from one degree Fahrenheit for every 100 feet to one degree for every 300 feet. Should these rates of increase continue for six or seven miles of depth, a very high temperature would soon be reached. Indeed, all observations go to show that there is a very high temperature in the interior of the earth. The increase of temperature is, of course, accompanied by an increase of pressure due to the overlying rocks; at a depth of 13,000 feet it has been estimated at 1000 tons to the square foot. At such pressures the strongest rocks are strained beyond their limit of elasticity. In the Mont Cenis tunnel a bed of soft granite was met with that continued to swell with irresistible force for some months—sufficient to crush an arched lining of two-feet granite blocks. The origin of the earth's high internal heat has been attributed to the residue of the original heat of the nebula from which the globe shaped itself, and also to the effects of the gradual gravitational compression of the earth's mass, and its condensation during growth. Although radium is not likely to be present in the deep-seated interior of the earth, possibly because of the enormous pressure there, still it has

been detected in all igneous rocks, especially in pegmatites, and the quantity in the crust as a whole is believed by R. J. Strutt to be sufficient to account for the temperature gradient, and to indicate that the acid crust cannot be more than forty miles in thickness, otherwise the outflow of heat would be greater than the amount actually observed. It has already been pointed out that there is more radio-active matter in the red clays of the ocean deeps than in any continental strata. We cannot tell why this should be so, but there are indications that it is very closely connected with the rate of deposition of the marine deposits.

GLOSSARY

Anabolism.—*See* Metabolism.

Aragonite—A mineral (calcium carbonate) identical with calcite in chemical composition, but differing from it in crystalline form (rhombic) and in some of its physical properties.

Benthos.—A term applied to those organisms which live attached to, or move over, the sea-floor.

Biosphere.—The sphere of living things found where there is a meeting of the atmosphere, the hydrosphere, and the lithosphere. *See* Geospheres.

Bipolar.—A term applied to identical or allied species, genera, and families which occur both towards the Arctic and Antarctic regions, but are unknown in the intervening tropical regions.

Calcite.—The rhombohedral form of calcium carbonate (known also as calcspar).

Catalytic Substances are those capable of bringing about a chemical reaction, even when applied in very small quantities, without themselves undergoing any diminution in quantity. No trace of the catalytic substance appears in the final products of the reaction.

Centrosphere.—The geosphere occupying all the central portion of the globe, believed to be solid as steel, largely made up of metals and metalloids with imprisoned gases, and having a mean density exceeding 5.

Colloidal.—A solid may be distributed through a liquid either heterogeneously (in suspension) or homo-

geneously (in solution). When the subdivision of a suspended substance is so minute as to make its retention by filter paper impossible, the solution is known as a *colloidal solution.*

CONTINENTAL EDGE.—The junction between the continental shelf and the continental slope, usually found at a depth of about 100 fathoms and indicated by a change of gradient.

CONTINENTAL SHELF.—That part of the ocean-floor lying between the shore-line and the 100-fathoms line; the gradient is usually very gentle, with higher portions called coast-banks.

CONTINENTAL SLOPE.—That part of the ocean-floor lying between the 100-fathoms line and the mean sphere level (1700 fathoms); the gradient of the bottom is usually much steeper than in shallower and deeper water.

DEEPS.—Those parts of the ocean in which depths greater than 3000 fathoms have been recorded.

DENSITY.—The density or specific gravity of sea-water is the ratio of a certain volume of salt water to that of an equal volume of fresh water at 39.2° F. The temperature at which the density is measured must be stated, as the densities of liquids vary greatly with temperature. Since the density of sea-water depends only on temperature and salinity, if the density is always measured at the same standard temperature, or corrected to it, the differences of density are due to differences of salinity alone.

ENZYMES.—Substances eminently characteristic of living matter; they are catalytic agents, as a rule soluble in water, in salt solution, or in glycerine, and are effective only in one reaction. They cause the formation of anti-enzymes in animal blood. They are colloidal in nature, and are unable to resist boiling temperatures.

GEOSPHERES.—The globe may be regarded as being made up of concentric spheres, the atmosphere, the hydro-

sphere, the biosphere, the lithosphere, the tektosphere, and the centrosphere; these are known as geospheres.

HYDROSPHERE.—The aqueous envelope of the globe, including the ocean, lakes, rivers, and the moisture which the atmosphere always contains, and the water which has penetrated deep into the lithosphere.

ION.—A form of molecular aggregation of matter in aqueous solution. An inorganic salt, base, or acid is partly split, when in solution, into ions. The metals mostly give cations, which carry a negative electrical charge and go to the positive pole in electrolysis. Acid radicals and certain non-metals form positively charged anions. In any solution the total negative charges on the cations exactly balance the total positive charges on the anions. It is impossible to isolate ions as such; when compelled to assume the solid state, they combine with one another to give electrically neutral molecules.

KATABOLISM.—*See* Metabolism.

LITHOSPHERE.—The rocky crust of the earth, a designation corresponding with atmosphere, hydrosphere, etc. *See* Geospheres.

MEAN SPHERE LEVEL.—The level of the lithosphere if smoothed off and covered by the ocean, which would then be of a uniform depth of about two miles (1700 fathoms).

METABOLISM.—The property characteristic of living matter of assimilating substances different from itself, of building them up into its own substance (anabolism), and of again decomposing these complex molecules into simpler ones (katabolism), with production of energy in the form of heat, movement and electrical phenomena. Metabolism results not only in the generation of energy, but also, if anabolism be in excess of katabolism, in increase of bulk and consequent growth and reproduction.

Minimum, Law of the (Liebig).—This well-established agricultural law is applicable also to the ocean. A plant requires a certain number of food-stuffs if it is to continue to live and grow, and each of these food-substances must be present in a certain proportion. If one of them be absent, the plant will die; if it be present in minimal proportion, the growth will also be minimal. This will be the case no matter how abundant the other food-stuffs may be. Thus the growth of a plant is dependent on the amount of the food-stuff which is presented to it in minimum quantity.

Mud-Line.—The depth at which fine mud forms on the sea-floor; along coasts facing the great oceans this depth is about 100 fathoms.

Nekton.—A term introduced by Haeckel to designate all pelagic animals that are able to swim against currents (*cf.* Plankton).

Neritic.—Belonging to coastal waters and bays, as opposed to "oceanic," found only in the open sea; the term was introduced by Haeckel, and is applied to both plankton and benthos. *See also* Pelagic.

Oceanic.—*See* Neritic.

Pelagic (Greek "pelagos," the open sea).—A term applied to deposits forming at abyssal depths of the ocean at a great distance from land, and also to organisms inhabiting the surface waters of the ocean far from coasts.

Photic Zone.—The surface waters down to the limit of penetration of sunlight, *i.e.*, 600 or 700 fathoms.

Phytoplankton.—Plant plankton. *See* Plankton.

Plankton.—A term introduced by Hensen and now used for all aquatic organisms passively carried along by currents (*cf.* Nekton).

Salinity.—The amount of total dissolved solids in unit volume of a liquid which holds salts and little or nothing else in solution; especially applicable to

natural waters. The salinity of sea-water is expressed in parts per thousand (as 35 per thousand); but it is a conventional quantity obtained by applying factors to the chlorine-content or specific gravity, since the direct determination of total dissolved solids cannot be effected with accuracy. *See also* Density.

Salt.—Any compound of an inorganic base with an inorganic acid, such as calcium carbonate, sodium sulphate, magnesium chloride, etc., produced by the replacement of the hydrogen of the acid by the metal of the base. (Common salt = sodium chloride, but the generic term "salt" connotes many other compounds in addition.)

Specific Gravity.—*See* Density.

Symbiosis.—Literally "living together": an intimate association between two organisms, such as an alga and a radiolarian, advantageous to both.

Tektosphere.—One of the geospheres; the shell of materials in a state bordering on fusion which surrounds the centrosphere, and upon which rests the lithosphere.

Viscosity.—The viscosity of liquids is the internal friction: the resistance to the motion of the molecules of the fluid body among themselves. It arises from the mutual attraction of the molecules, and diminishes as the temperature is raised and the molecules move farther apart.

CONVERSION OF MEASURES FROM BRITISH TO CONTINENTAL UNITS

DEPTH AND LENGTH.

1 fathom = 6 feet = 1·83 metres.
100 fathoms = 200 yards = 182·9 metres.
1000 fathoms = 1·829 kilometres = 1·136 English miles (or one geographical mile).
1 English mile = 5280 feet = 1·609 kilometres.

PRESSURE.

1 atmosphere = 760 millimetres of mercury.
= 29·9212 inches of mercury (approximately 30 inches).
= 14·697 lbs. per square inch (approximately 14·7 lbs.).

TEMPERATURE.

Fahrenheit.	*Centigrade.*	*Fahrenheit.*	*Centigrade*
0°	−17·78°	50°	10·00°
2	16·67	52	11·11
4	15·56	54	12·22
6	14·44	56	13·33
8	13·33	58	14·44
10	12·22	60	15·56
12	11·11	62	16·67
14	10·00	64	17·78
16	8·89	66	18·89
18	7·78	68	20·00
20	6·67	70	21·11
22	5·56	72	22·22
24	4·44	74	23·33
26	3·33	76	24·44
28	2·22	78	25·56
30	−1·11	80	26·67
32	0·00	82	27·78
34	+1·11	84	28·89
36	2·22	86	30·00
38	3·33	88	31·11
40	4·44	90	32·22
42	5·56	92	33·33
44	6·67	94	34·44
46	7·78	96	35·56
48	8·89	98	36·67
		100	37·78

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Plate I

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EXPLANATION OF THE PLATES

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